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ABSTRACT

This five-chapter document (part of a series on biology and human welfare) focuses on biological systems as energy sources and on the teaching of this subject area. Chapter 1 discusses various topics related to energy and ecology, including biomass, photosynthesis and world energy balances, energy flow through ecosystems, and others. Chapter 2 discusses the importance and reactions of photosynthesis. Chapter 3 examines various aspects of biofuels, including methane (biogas production, advantages and disadvantages of anaerobic biogas generators, biogas economics, and others). Chapter 4 offers a curriculum guide for teaching about biological systems as energy sources. It shows how the teaching of this subject area fits the aims of secondary school science education; offers suggestions for developing and implementing curricula which incorporate topics on biological systems as energy sources; and presents (in chart format) environmental aspects of biological education, listing concepts, principles, and/or topics with related practical experiences, teaching strategies, and values/skills fostered. Chapter 5 offers and describes various teaching and learning strategies, including descriptions of three student activities (such as making a model biogas generator). A list of references and resources is included. (JN)

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INTRODUCTION

As the end of the twentieth century approaches, the world faces an ever increasing energy crisis, since natural supplies of coal, gas and oil are dwindling rapidly. For the past fifty years, rapid industrial growth has been maintained and financed by cheap oil However, the 1973 OPEC oil price increase to some extent put a brake on oil consumption by making more people aware of extravagant usage. As a result, there was more demand for motor vehicles with greater fuel economy and more concern about better heat insulation in buildings. Nevertheless, the oil price rise made a major contribution to world inflation, particularly in the Developed World (North America, Western Europe, USSR, Japan, Australia, New Zealand and South Africa) where 25% of the world's inhabitants consume 80% of the fossil fuels and nuclear energy. Both directly and indirectly, this had a pronounced affect on the economies and aid to the Third World countries. For the majority of people in these countries, however, oil is not their major concern; the price is beyond them. Their needs are more fundamental; namely, how to obtain sufficient food and keep warm. As a result, theirs is a firewood economy and they spend a high proportion of their time and income in gathering wood. Indeed, firewood provides about 70% of the energy in most African countries and, in some countries like Tanzania, over 90%. The problem is exacerbated as populations increase because firewood becomes an even scarcer commodity and pressures on available wood become even more intense. In arid and semi-arid countries, it often leads to deforestation, which in turn results in loss of top soil. This has two major effects: (i) it leads to a build-up of silt in rivers, and (ii) it makes the establishment of new forests much more difficult.

Concern about basic energy requirements, whether affecting individuals or nations, has prompted scientists to explore a variety of alternative energy sources, as well as alternative technologies, though not with equal funding.

The focus here is on biological systems as energy sources, not because biological systems are necessarily better economically than other alternative energy sources (e.g. nuclear, solar, wind, wave and geothermal), but rather that there is much to learn from the great metabolic diversity of living organisms, especially micro-organisms. After all, certain living organisms "solved" the energy crisis some three thousand million years ago, when they became able to trap solar energy and transform it into chemical energy by photosynthesis. Furthermore, biological activities of the past are entirely responsible for the origins of fossil fuels upon which twentieth century economies are so dependent.

CHAPTER 1

Energy and Ecology

Biomass in Perspective

All organic matter (alive or dead) is collectively referred to as BIOMASS. Biomass is not only a source of fuel but also provides all our food and much of our fibre. To assess the value of biomass as an energy source, it is useful to start by asking a number of questions that permit a comparison to be made with other energy sources. Whilst these questions may not be all-embracing, they will help to focus on some of the issues raised in this article.

1. How abundant and readily available is the energy source?
2. Can it be stored easily?
3. Can it be retrieved from storage and readily utilised for a variety of purposes?
4. Is it a constantly renewable source of energy?
5. Is it safe?
6. Does it cause pollution?
7. How much energy is gained from the system in relation to the energy put into it? (i.e. output : input ratio).
8. How expensive is one form of energy in relation to another? Does this vary with site specificity?
9. Is the energy source a practical proposition?
10. Is the technology sufficiently advanced to allow its use on a large scale?
11. Is it a sound socio-economic proposition for all members of a community? i.e. can they all afford it?
12. What competitive or conflicting demands are made on the energy source with respect to other requirements? (e.g. land area for housing, growing food, recreation, etc.).

At present, it is thought that biomass, mainly in the form of wood, straw and animal wastes, provides about 15% of the world's energy. It is mostly burnt inefficiently in rural areas of the Third World and the task for scientists here is to improve efficiency of use with minimum expense. By doing so, such research could pave the way for much greater use of biofuels in the future, when fossil and fissile energy reserves are depleted.

Some Important Terms

Autotrophs and heterotrophs. Living organisms are either autotrophic or heterotrophic. Autotrophic organisms synthesise complex organic matter from simple inorganic compounds; namely, by the reduction of carbon dioxide into sugars and fats and the incorporation of inorganic nitrogen and sulphur into amino acids. Virtually, all autotrophs obtain energy for these processes by trapping solar energy. The only exceptions are certain chemo-autotrophs (bacteria) that utilise partially reduced (or incompletely oxidised) sources of material, such as nitrite, sulphide or ammonia. Heterotrophs, by contrast, use the organic compounds synthesised by autotrophs to supply their energy, carbon and nitrogen requirements.

Oxidations and Reductions. Fundamentally, energy moves through living organisms by shuttling electrons and protons around on a carbon skeleton. Reductions are always energy-conserving processes involving the gain of electrons (or electrons and protons). Oxidations are always energy-yielding processes and can be considered to be a loss of electrons (or electrons and protons) or direct addition of oxygen. It follows that as one substance is oxidised another is reduced. Energetic electrons arise in the first place from the addition of quantum energy (light energy) to chlorophyll molecules in the process of photosynthesis. To measure the oxidising-reducing potential of any substance relative to another, biologists and biochemists use a standard redox scale. The units of measurement used are volts and the standard electrode is the hydrogen electrode. Details need not concern us here; sufficient to say that the more negative the value of the redox couple (under standard conditions), the greater is the reducing potential of that couple, whereas the more positive the value of the redox couple, the greater is the oxidising potential. Some mid-point standard potentials of couples are given below (molar concentrations; pH 7.0; 25°C) :

	E_o (volts)
$2H^+ + 2e^- \rightleftharpoons H_2$	- 0.42
$Ferredoxin_{(ox)} + 2e^- \rightleftharpoons Ferredoxin_{(red)}$	- 0.43
$NADP^+ + 2H^+ + 2e^- \rightleftharpoons NADP + H^+$	- 0.32
$NAD^+ + 2H^+ + 2e^- \rightleftharpoons NADH + H^+$	- 0.32
$Plastoquinone_{(ox)} + 2e^- \rightleftharpoons Plastoquinone_{(red)}$	0.00
2 cyt c_1 (ox) + $2e^- \rightleftharpoons$ 2 cyt c_1 (red)	+ 0.22
2 cyt c (ox) + $2e^- \rightleftharpoons$ 2 cyt c (red)	+ 0.25
$O_2 + 2H^+ + 2e^- \rightleftharpoons H_2O$	+ 0.82

Enzymes. Enzymes are proteins that speed up (catalyse) the essential chemical reactions of life. They operate at comparatively low temperatures and within a relatively narrow range (0°-60°C). During a reaction, enzymes remain chemically unchanged though conformational changes usually occur within their physical structure. Enzymes are normally very specific in their affinity for a substrate. Furthermore, many enzymes are subject to allosteric control (i.e. control at another site other than the active site) by other molecules of smaller molecular mass.

Co-enzymes. Co-enzymes are organic substances (not protein) of much smaller molecular mass than enzymes. They facilitate the action of enzymes. Many co-enzymes are electron carriers (e.g. $NADP^+$, NAD^+, flavins); others, like ATP, are involved in phosphate group transfer. In all processes involving the reduction of simple molecules (e.g. the fixation of N_2 to NH_3; the reduction of 'CH_3' groups to methane, and the reduction of CO_2 to sugars) both enzymes and co-enzymes are involved. Co-enzymes are usually involved in transferring some 'group' of atoms from one substrate to another. Unlike the enzyme itself, the co-enzyme is normally changed during the course of the reaction by either gaining or losing the group of atoms to be transferred. Reconversion to the original form takes place independently in another reaction and possibly even in another part of the cell.

Ecosystem. An ecosystem is any identifiable unit in nature consisting of both living organisms and their physico-chemical environment whereby there is a continuous exchange of inorganic materials between the living organisms and their environment. Since light provides the energy to drive the system, photosynthetic organisms (producers) are essential for incorporating inorganic materials from the environment and decomposers are essential for returning inorganic materials to the environment.

Community. A group of interacting populations of different species with an ecosystem.

Ecological Efficiency. Ecological efficiency is the percentage of energy in the biomass by one trophic (feeding) level in the ecosystem that is incorporated into biomass produced by the next highest trophic level. The energy available to the system as a whole will depend upon the solar energy trapped by the primary producers in photosynthesis.

Photosynthetic Efficiency. The percentage of light energy assimilated by plants; based either on gross production or on net production. Net production is probably the better measurement because it takes into account the loss of energy via respiration to maintain the producer population.

Biomass. Biomass is normally expressed in units of dry weight per unit area (e.g. g m^{-2}). Trees and shrubs can put biomass into long-term storage by conversion to woody material.

Productivity. Productivity is the rate at which energy or dry weight of material accumulates in a unit area per unit of time

(e.g. $kJ^{-2}yr^{-1}$ or kg dry wt $m^{-2}yr^{-1}$). Productivity is normally expressed as a net rate, that is, accumulation after respiration has been accounted for. Primary production is the base on which the biological community is founded. The annual primary productivity of plants on Earth is quite extraordinary. Something in excess of 100 million tonnes of dry organic matter is produced on land and about 50 million tonnes in the oceans.

It does not necessarily follow that a high biomass will give a high rate of production. For example, if one compared the biomass of some simple planktonic algae within 1 m^2 with the biomass in a similar area of tropical forest, the difference in biomass is likely to be 80-100 fold larger in favour of the tropical forest. Conversely, given a constant supply of nutrients, net production could be nearly twice the rate for algae as for the tropical forest. Under such circumstances, the ratio of net production to biomass (P : B ratio) for the algae could be 140 times greater than for the forest. High biomass normally means that a certain proportion of net production has accumulated as living tissue over an undisclosed time.

Factors affecting productivity include : (i) the type of plant; (ii) position of leaves on the stem; (iii) arrangement of leaves around the stem; (iv) angle of leaves on stem; (v) shape of leaves; (vi) internal design of leaves; (vii) age of leaves; (viii) the leaf area index (LAI), which is a measure of the size of the system, and is defined as the total area of leaves/unit area of land; (ix) the unit leaf area (ULA), which is a measure of efficiency, and is defined as the mean rate of production as dry weight of biomass/unit leaf area - in theory the highest rate of dry biomass production equals LAI x ULA, but clearly there is an optimum value, because as LAI rises, ULA falls, since shading reduces the average amount of light per leaf; (x) the rate of photosynthesis and photosynthetic efficiency; (xi) the rate of respiration; (xii) the rate of photorespiration; (xiii) availability of water and the rate of transpiration; (xiv) rate of water absorption by roots; (xv) addition of fertiliser and/or nutrients present in the soil; (xvi) physical factors in the environment, such as light intensity, light duration, temperature and CO_2 concentration; (xvii) crop husbandry, such as soil preparation, weeding and crop rotation; (xviii) age of plant.

Yield. That part of the crop which is harvested and used. When productivity is increased by man's intervention, the result is normally an increase in yield. Yield of a particular crop can be increased by growing it as a monoculture to which regular watering, extensive weeding and application of fertilisers are made. These treatments, however, are either intensive in their use of labour or energy intensive by the use of machinery and manufacture of fertilisers. In both cases, there is an increase cost involved in increasing yield.

Photosynthesis and World Energy Balances

Solar radiation is not uniform over the world's surface. Surprisingly, however, the differences in total annual solar radiation between various countries is never more than three-fold. For example,

the difference in total solar radiation between Australia and the United Kingdom is only a factor of 2; between the U.K. and Saudi Arabia (the area within the greatest amount of solar radiation) is only about a factor of 3, although solar energy is more unreliable in the U.K. Given these differences, the quantity of solar radiation annually incident over the earth's surface is estimated at 3×10^{24} J. This represents about 70 times the present (proven) total of fossil fuel energy reserves (4.3×10^{22} J). However, only a small proportion (about 0.1% or 3×10^{21} J) of this vast energy influx is utilised in photosynthesis. Why is this?

(i) Only 50-60% is actually available for absorption by marine and terrestrial plant life. The remainder is reflected by deserts, ocean surfaces, snow, ice, etc.

(ii) Of the potential energy available for absorption, only 43% falls in the photosynthetically-active region (PAR), i.e. between the wavelengths 400 nm - 700 nm.

(iii) Even under optimal conditions of leaf arrangement, there is at least a 20% loss due to reflection, transmission and inactive absorption by the leaves.

(iv) The efficiency of absorbed energy converted to organic material in the photosynthetic reactions is not more than 23%.

(v) There is a further 40% loss in actual conversion efficiency as a result of plant respiration.

Table 1(a). High short-term productivities and photosynthetic efficiency (PE). (Data from various sources).

Location	Species	Yield g/m^2 day dry wt.	P.E.
UK	Ryegrass	28	2.5
UK	Sugar beet	31	4.3
UK	Kale	21	2.2
UK	Potato	23	2.5
UK	Maize (C-4 plant)	24	3.4
El Salvador	Napier grass (C4)	39	4.3
Hawaii	Sugar cane (C4)	37	3.8
California	Sorghum (C4)	51	3.0

Table 1(b). Annual productivities and photosynthetic efficiencies.

Location	Species	Yield t/ha yr dry wt.	P.E.
UK	Ryegrass	23	1.3
UK	Sugar beet	23	1.1
UK	Kale	21	1.1
UK	Potato	11	0.5
UK	Maize (C4)	17	0.9
El Salvador	Napier grass (C4)	85	2.4
Hawaii	Sugar cane (C4)	66	1.7
California	Sorghum (C4)	48	1.4

On these figures the maximal photosynthetic efficiency obtainable is only 5-6%; in reality, most plants under field conditions rarely exceed 1-2% (see Table 1 above). Even so, only about 0.5% of the carbon fixed in the process of photosynthesis is actually consumed as food by the earth's 4.5×10^9 people and there is therefore considerable scope for using the products of photosynthesis in other ways. These points are summarised in Table 2.

Table 2.

Estimates		
(1)	TOTAL SOLAR ENERGY incident on earth	3×10^{24}J/yr
(2)	PHOTOSYNTHESIS fixes	3×10^{21}J/yr (0.1% of (1) above. Equiv. 2×10^{11} tonnes organic carbon)
(3)	FOOD CONSUMED by	4.5×10^9 people is 1.5×10^{19}J/yr (0.5% of (2) above)
(4)	FOSSIL FUEL RESERVES (proven)	5×10^{22}J
(5)	CONSUMPTION OF ENERGY (1970)	3×10^{20}J/yr

Photosynthesis fixes x 10 of (5) above and x 200 of (3) above

It is the only renewable source of energy supplying FUEL, FOOD and FIBRE.

Data after D.O. Hall (1979). *Biologist* 26 (1), p.17.

Does it matter that for practical purposes photosy thetic efficiency is only about 1-2%?

Obviously, it would be of considerable advantage in feeding the world's population if photosynthetic efficiency could be doubled; partly because biomass would increase, but also because less land (or sea) area would be needed to grow the same quantity of food. Similarly, if biomass is to provide a significant proportion of our energy requirements in the future, a greater photosynthetic efficiency would again mean that less land is needed to support fuel crops.

Can photosynthetic efficiency or crop yield be improved?

Biochemical and physiological research over the past 20 years has given a much better understanding of photosynthesis, especially in relation to other metabolic pathways. Consequently, greater use is being made of carbon-4 plants such as maize, sugar-cane, sorghum and Napier grass, because under semi-tropical conditions they are photosynthetically much more efficient. This is important when considering food crop plants or energy crop plants.

From the point of view of biofuels, two other possibilities are being considered: (1) The use of very fast growing plants, such as the water hyacinth, *Eichornia crassipes*, and (2) certain plants of the species *Euphorbia* which produce hydrocarbon-like compounds of relatively low molecular weight. Furthermore, relatively simple practical steps, such as more efficient harvesting and better post-harvest storage, could be implemented almost immediately.

Another area of intensive research is in plant genetics. Selective breeding and genetic engineering, not only offer the possibility of higher yielding plants, but genetic engineering should soon enable a greater number of crop plants to fix atmospheric nitrogen. At present, only legumes fix atmospheric nitrogen via symbiotic bacteria in their root nodules. Genetic engineering is on the threshold of being able to transfer the gene conferring the ability to house the nitrogen-fixing bacterium into a variety of new host plants, particularly staple crops, such as wheat, barley and rice. The major challenge at present is that the nitrogenase enzymes must operate in the absence of oxygen. This obstacle may take some time to overcome before nitrogen fixation by agriculturally important crops becomes a reality.

Energy Flow through Ecosystems

In order to evaluate the feasibility of using biomass as an energy source, it is first necessary to consider briefly the nature of ecosystems and the balance of events within them.

An ecosystem is a self-maintaining community of living organisms dependent only upon available sunlight, water and simple nutrients. What we examine in the ecosystem are the interactions between the biological, chemical and physical components of that system.

All living organisms require energy to do work. This energy enters ecosystems as light and is converted to chemical energy by plants during photosynthesis. The rate at which plants assimilate the energy from sunlight is referred to as primary production. Primary production is the foundation stone upon which other trophic or feeding levels of the communities are built. For self-maintenance, however, the ecosystem must contain decomposing organisms capable of recycling essential nutrients. A generalised model of an ecosystem, demonstrating the flow of energy (—) and nutrients (---) (Fig. 1).

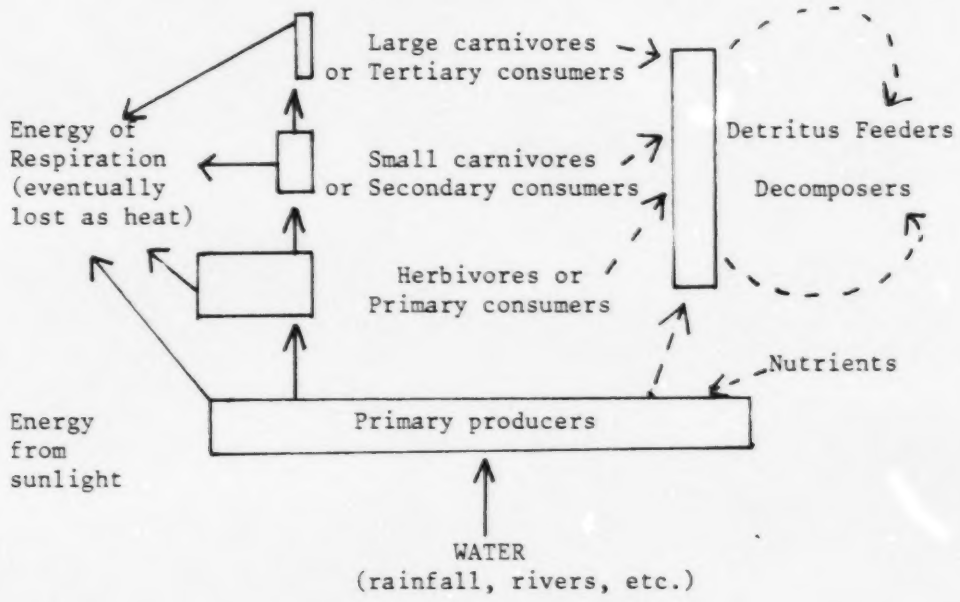


Fig. 1.

Energy flow through an ecosystem is an important consideration that should be touched upon here because it gives an indication of the stability of the system. Several authors have likened it to a bank account, where it is important over a long period of time that income either equals or does not exceed expenditure. Likewise with an ecosystem; although daily and seasonal fluctuations may cause energy credits or energy deficits (just like pay cheques and bills in the bank account), an ecosystem cannot go on indefinitely losing energy. Consequently, like the strong bank account in balance, the tropical forests or temperate woodlands are more stable, insofar as they have a greater store of biomass energy as well as more elaborate feedback controls over the recycling of nutrients and top-soil stability. By contrast, a monoculture is a much more unstable system, with few checks and controls over the recycling of nutrients and top-soil stability. Such matters need to be considered very carefully when growing food or fuel crops, despite the understandable desire to cut down large areas of natural vegetation to plant such crops.

Measuring energy flow with accuracy is difficult and at times an impossible task. To take just one example. Net primary production is measured by looking at the annual increase in plant

biomass. This may be relatively easy in aquatic systems with simple photosynthetic green algae (annual growth), but in most terrestrial ecosystems (grasslands, forests) it is an on-going process from year to year (perennial growth) and should strictly involve harvesting, and then drying and weighing each plant, each year. Clearly, this is an impossible task. It is feasible to get some idea of the above ground productivity from harvesting each year but the root system and its productivity below ground is impossible in most cases. Consequently, harvesting methods measure net annual above ground productivity.

One of the most thorough studies of energy flow in an ecosystem was carried out by Odum in 1957 at Lake Silver Springs, Florida. Fig. 2 is based on Odum's data, though much simplified. (Values given as kJ $m^{-2}yr^{-1}$).

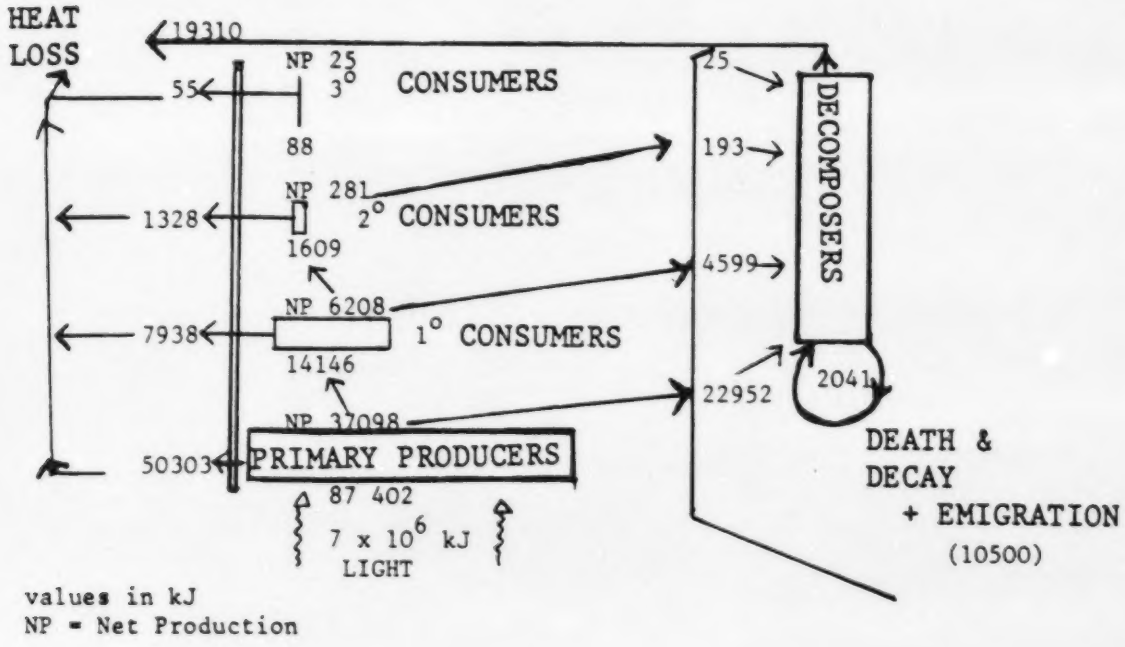


Fig. 2.

Some points to note :

(i) The photosynthetic efficiency of this system (annual mean) is 1.2%

$$\frac{8.7 \times 10^4}{7 \times 10^6}$$

(ii) The enormous amount of energy lost via respiration, etc. as heat.

(iii) The importance of the size of the 'energy base', i.e. the primary producers in determining the number of trophic levels.

(iv) The importance of the decomposer/detritus feeders in recycling nutrients for the system.

(v) There is a loss of energy via emigration (dead and alive) from the system accounting for 10,500 kJ.

How does this ecosystem compare with others that have been studied?

The relative importance of detritus-based as compared with predator-based food chains varies considerably among communities. For example, in ocean systems, phytoplankton comprise the energy base of the food chain. Turnover rate is very high because it is a predator-based food chain. Exploitation of the producer base by primary consumers is normally 60% and sometimes considerably more. Ecological efficiency from one trophic level to the next is also high. Consequently, more energy is potentially available to support the next trophic level and so on. It is not uncommon to find, therefore, 5 or 6 trophic (feeding) levels in ocean ecosystems. By contrast, the ecological efficiencies of most terrestrial ecosystems are low. For example, in deciduous forests, trees are the dominant primary producers. Large amounts of biomass energy are 'locked up' as non-photosynthetic material. Turnover rates in terms of production and consumption are low and exploitation of the system by primary consumers is normally about 1-3%. Photosynthetic efficiency is also low, with the detritus feeders and decomposers consuming a high proportion of production. Correspondingly, the number of trophic levels supported by forests and woodlands is rarely more than 3 and for temperate grasslands rarely more than 4.

How long does it take for energy to flow through an ecosystem?

This is an important question because the dynamics of an ecosystem cannot properly be appreciated without understanding how long it takes for a particular packet of energy and associated organic compounds to pass through it. The transit time, as it is called, also has important consequences when considering energy crops. In measuring transit time, the following factors must be considered : (i) living biomass ($g\ m^{-2}$); (ii) net productivity ($g\ m^{-2}yr^{1}$); (iii) accumulation of dead organic matter (or litter) ($g\ m^{-2}$) and (iv) rate of litter fall or build up ($g\ m^{-2}yr^{-1}$).

$$\text{Transit time (yr)} = \frac{\text{Living biomass + litter } (g\ m^{-2})}{\text{Net productivity + rate of litter fall } (g\ m^{-2}yr^{-1})}$$

The transit time does as a result vary considerably from ecosystem to ecosystem. For example, it is very rapid in oceans, lakes and streams, i.e. in a matter of 10-20 days, but in most forest systems, whether temperate or tropical, transit time is of the order of 25 years. Most marshes and grasslands fall between these two extremes with figures ranging from 3 to 10 years.

Ecologists usually measure energy flow directly in the field by following the movement of organic substances tagged with radio-active phosphorus (^{32}P) and observe the time taken for the label to reach different trophic levels in the community.

What factors contribute to the development and stability of an ecosystem?

Developmental (unstable)	Mature (stable)
1. High production efficiency.	1. Low production efficiency.
2. Susceptible to invasion and colonisation.	2. Resistant to further invasion and colonisation.
3. Few species.	3. High species diversity.
4. Low biomass stability.	4. High biomass stability.
5. Rapid exchange of nutrients with few feedback controls. Detritus relatively unimportant.	5. Slow exchange of nutrients with extensive feedback controls. Detritus important in nutrient regeneration.
6. Little stratification.	6. High level of stratification.
7. Broad niche specificity.	7. Narrow niche specificity.
8. P/R > 1.	8. P/R 1.

These points have been made to emphasise that structural and bioenergetic considerations have an important bearing on managed as opposed to natural communities. First, maintenance of a monoculture requires a greater energy input than a natural system; it is also more labour intensive and more expensive. Secondly, it is a more unstable system, inasmuch as it is more susceptible to invasion and vagaries of the environment. Thirdly, the importance of recycling materials together with the natural checks and balances imposed within mature ecosystems must be considered carefully, before hastily embarking on the extensive removal of natural vegetation in favour of food or fuel crops.

CHAPTER 2

Photosynthesis

Life on earth to-day is driven by the energy from sunlight. Although a few anaerobic bacteria can utilise the longer wavelengths of light for photosynthesis, by generating electrons from substances like organic acids or hydrogen sulphide (Fig.3), all green plants and blue-green algae carry out photosynthesis essentially as shown in Fig.4.

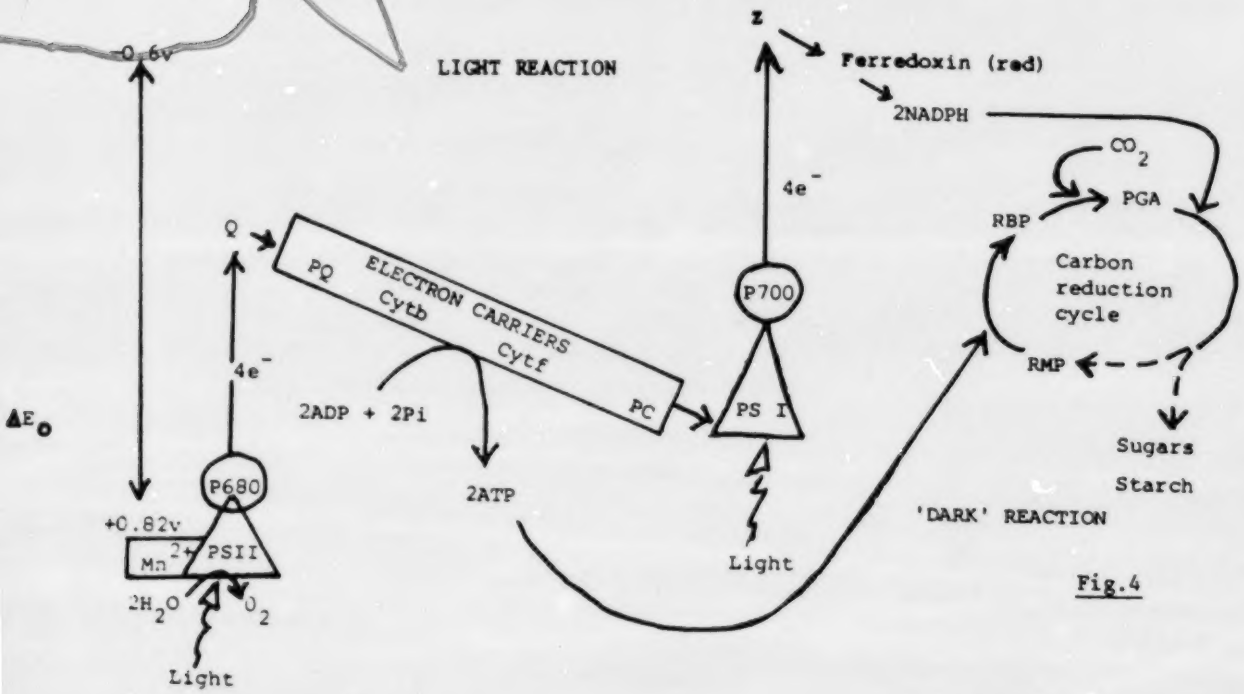


Fig.4

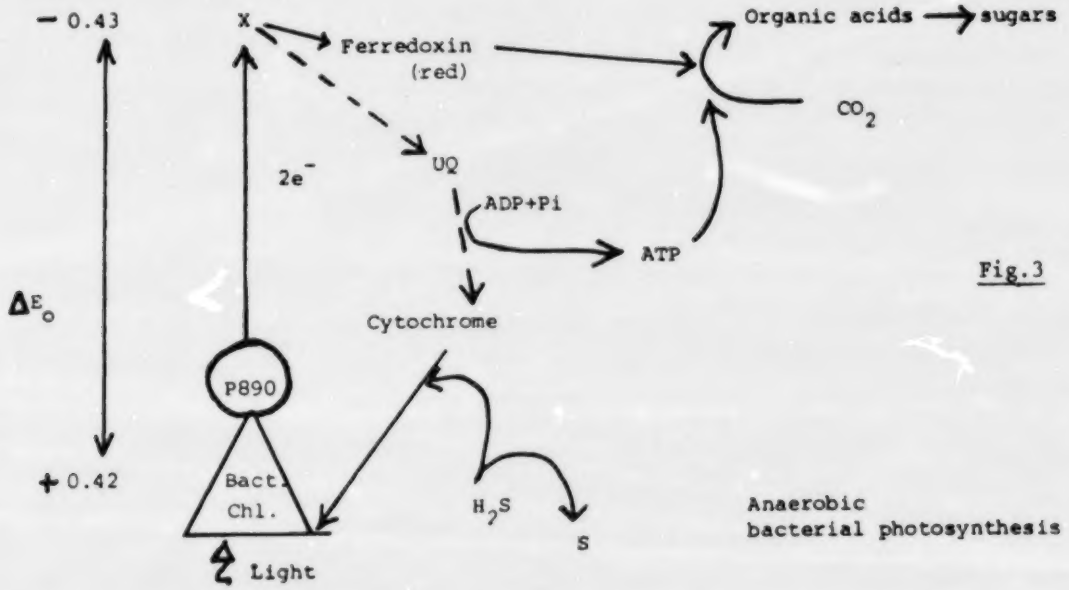


Fig.3

Anaerobic bacterial photosynthesis

There are small differences in the wavelengths of light utilised dependent upon the specific ecological niche of the organism. For example, many red algae have a greater sensitivity to the shorter wavelengths of light, because they normally exist either partially or completely emersed in sea water, which tends to filter out the longer wavelengths. Photosynthesis, as depicted in Fig. 4, is called oxygenic photosynthesis because O_2 is given off as a by-product in the photolysis of water. In this scheme (compared with Fig. 3), water acts as the source of electrons. Whilst water is much more abundant and more readily available than H_2S, from a redox consideration alone, it is less suitable, since the $2H^+ + 2e^- \rightleftharpoons H_2$ redox couple is much more positive (+ 0.82 v) than the $2H^+ + 2e^- + S \rightleftharpoons H_2S$ couple (+ 0.43 v). This feature accounts for the presence of two photosystems in oxygenic photosynthesizers, because electrons from water cannot be raised to the level required to reduce CO_2 to sugars in one step (i.e. there is insufficient energy in one 'jump').

Oxygenic Photosynthesis

Essentially there are three steps :

(i) the light driven photolysis of water releasing energetic electrons;

(ii) the synthesis of ATP and NADPH in the light reaction, essential to drive the reduction of CO_2;

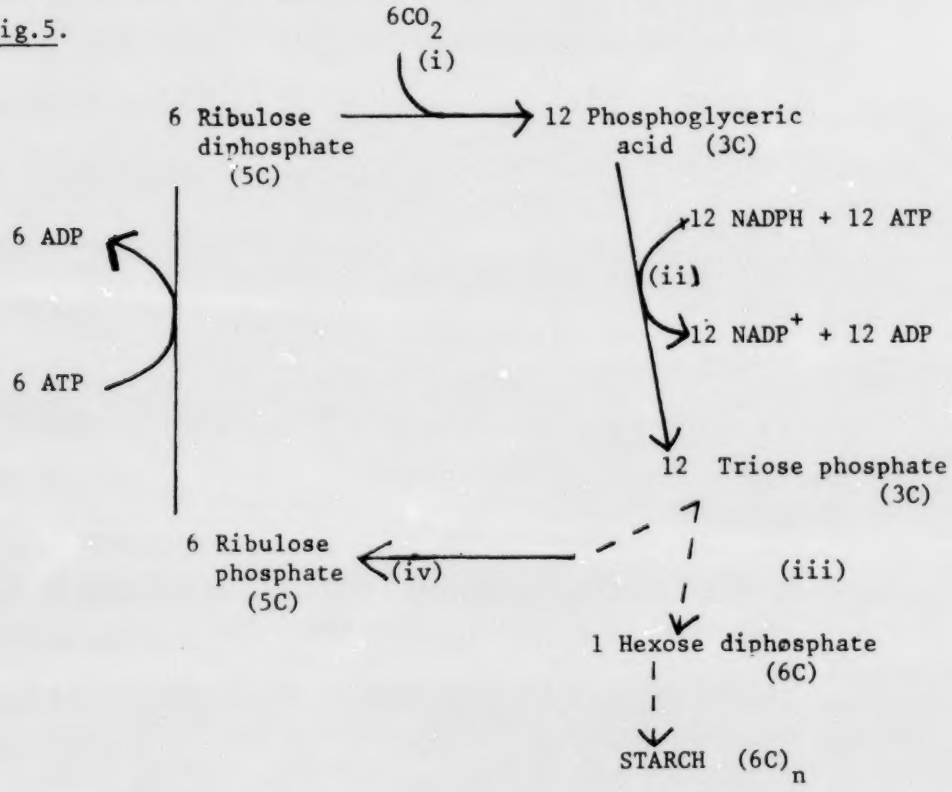
(iii) the reduction or fixation of CO_2 in the so called 'dark reaction'.

Experimental evidence shows (i) that chloroplasts are the exclusive sites of these three steps in photosynthesis; (ii) that the light driven reactions occur within the internal membranes (grana) of the chloroplast, whereas fixation of CO_2 occurs in the soluble stroma (see plate 1); (iii) that two identifiably different photosystems exist with different wavelength sensitivity.

The light reaction. The two photosystems (abbreviated PSI and PSII) are responsible for trapping and harvesting the quantum energy from light. Each photosystem comprises the light gathering arrays of chlorophyll a and b (about 200-300 molecules in each photosystem) bound in association with a light-harvesting protein (LHP) and carotenoids which initially absorb light energy. The excitation is passed to the photosynthetic centre of the photosystem - a single molecule of specialised chlorophyll a referred to as P_{700} and P_{680} respectively. It is these molecules which, when excited, can reduce ferredoxin and plastoquinone (PQ) respectively via intermediates (Q and Z), whose detailed chemistry is as yet unknown. PSI, PSII and the associated electron carriers comprise a functional unit or quantasome. The granal membranes house many quantasomes.

Dark reaction (C-3 plants). In most cases (particularly in algae and temperate plants), the first product formed after condensation of CO_2 with the 5-carbon sugar ribulose biphosphate (RBP) is phosphoglyceric acid (PGA). This is a 3-carbon molecule, there being 2 molecules of PGA produced from the condensation of one molecule of CO_2 with 1 molecule of RBP. Evidence for this was first confirmed from autoradiographic studies on single-celled green algae by Calvin and his co-workers in the early 1960's. For each turn of the cycle one-sixth of the carbon is synthesised as hexose. A simplified version of the Calvin or carbon reduction cycle is shown in Fig. 5.

Fig.5.



Simplified version of the carbon reduction cycle :

(i) carboxylation - CO_2 condensation;

(ii) reduction;

(iii) synthesis of hexose sugars and starch;

(iv) regeneration of RDP.

Fig. 5.

Dark reaction (C-4 plants). Photosynthetic efficiency of C-3 plants is reduced by a process called photorespiration (see below). This occurs when light intensity is high, oxygen concentration is high, CO_2 concentration is low and water use efficiency is low (i.e. the ratio of the mass of CO_2 assimilated to water transpired). Certain tropical grasses, such as maize, sugar cane, sorghum and Napier grass, have overcome the problem of photorespiration by anatomical separation of the light reaction (alongside effective concentration of CO_2 into a C-4 acid) from the dark reaction. In other words, the centrally placed bundle sheath cells in which the dark reaction primarily occurs contain chloroplasts with few or no grana but possess conspicuous starch granules. These cells are surrounded peripherally by mesophyll cells containing chloroplasts with prominent grana. The biochemical pathways involved are summarised in Fig. 6.

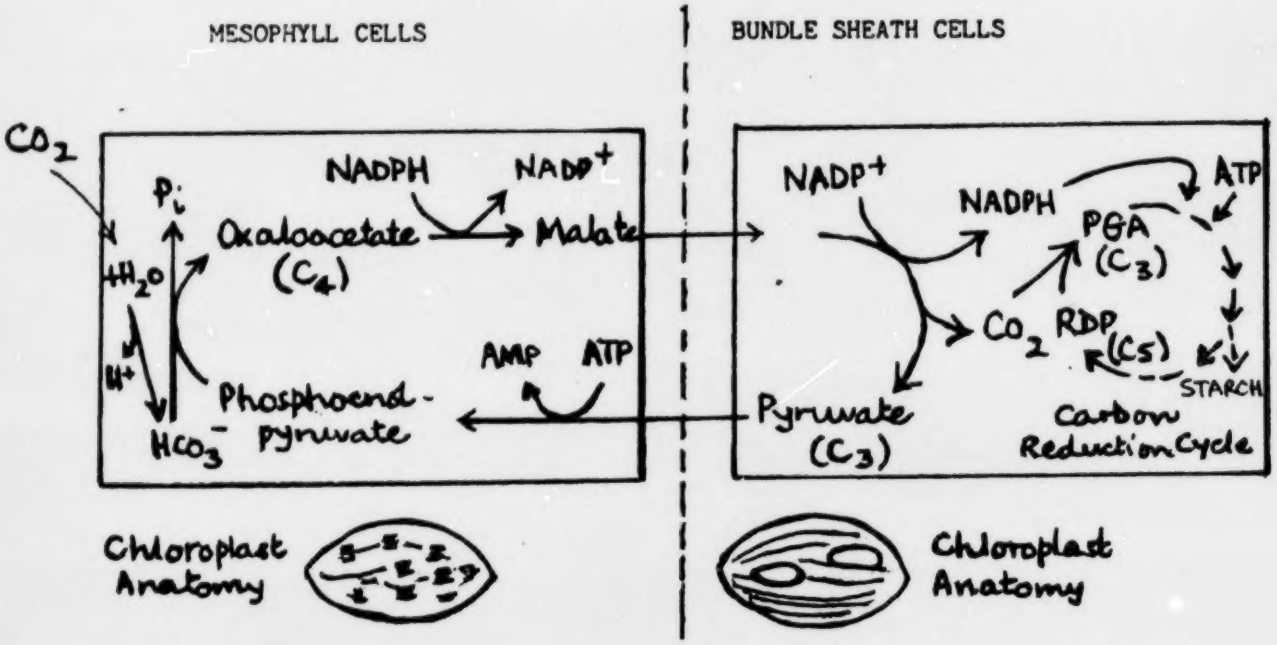


Fig. 6.

Points to note :

(i) The limited amount of CO_2 is first converted to the bicarbonate ion which interacts with phosphoenol pyruvate (PEP) via a key enzyme PEP carboxylase. The main product of the reaction is oxaloacetate, an organic acid containing 4 carbon atoms (hence C-4 metabolism).

(ii) Oxaloacetate is reduced to malate, allowing the "locked up" CO_2 to be transported to the bundle sheath cells, where malate is decarboxylated to pyruvate, liberating CO_2 for the Calvin cycle. Should any CO_2 escape, it will be mopped up and converted to oxaloacetate as it diffuses peripherally to the mesophyll cell.

(iii) A key enzyme in maintaining the availability of PEP from pyruvate (thermodynamically a very difficult step) is PEP dikinase, which is able to couple the energy from two phosphate residues in ATP for the purpose. The utilisation of ATP is, of course, an energy consuming step for C-4 plants, but since light is not a limiting factor, ATP production via photophosphorylation (light-driven ATP synthesis) is no problem. C-4 plants therefore expend energy to compensate for the limitations on CO_2 availability, but thereby virtually eliminate energy loss by photorespiration.

Cam plants (CAM - Crassulacean Acid Metabolism). A further modification of the dark reaction is seen in plants of the family *Crassulaceae* (e.g., cacti, Euphorbia, orchids, broom, etc.). Here, separation of light and dark reaction is not by anatomical location but in time. It is a special adaptation to minimise photorespiration and water loss in conditions of low water availability, high light intensity and high temperature. A simplified version of the biochemical pathway is outlined in Fig. 7.

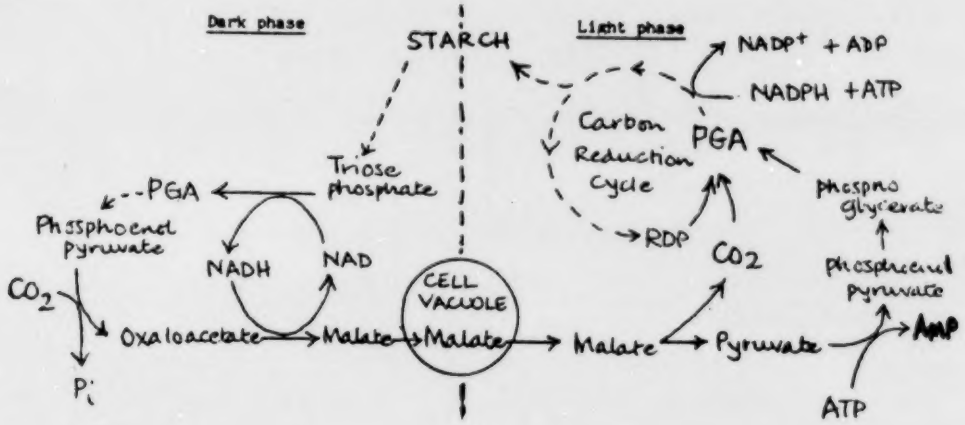


Fig. 7.

Points to note :

(i) To minimise water loss during much of the day, the stomata of the leaves remain closed, but this also minimises CO_2 exchange. Stomata only open fully in less intense light and also when the plant is not under water stress.

(ii) Whilst some CO_2 is fixed directly into PGA during the day, most of the CO_2 is fixed at night, as malate, when the plant is not under water stress. The cell vacuole plays a crucial role in the storage of malate and other C-4 acids.

(iii) Unlike the tropical grasses, C-4 metabolism of CAM plants occurs in a single cell type rather than across two tissues.

Photorespiration. The first and fundamental step in the Calvin cycle is the condensation of CO_2 with RDP. This step is controlled by the enzyme ribulose biphosphate carboxylase. When the concentration of CO_2 is relatively high compared with oxygen concentration, the formation of 2 molecules of PGA is favoured from 1 molecule of CO_2 plus 1 molecule of RBP. When CO_2 concentration falls and O_2 concentration rises, O_2 competes with CO_2 for the active site of RBP carboxylase. The end result is the production of only 1 molecule of PGA along with a molecule of phosphoglycollate (a 2-C substance). The production of phosphoglycollate does contribute indirectly to amino acid metabolism, but overall it is energetically a wasteful process, since it reduces photosynthetic efficiency and yield. In recent years, research has centred on reducing the levels of photorespiration by the use of specific chemical inhibitors and, on a long-term basis, by genetic manipulation.

Respiration

The details of aerobic respiration are not of great concern in a study of biomass as fuel. Sufficient to say that all living organisms respire to provide energy for movement, growth and reproduction. In any consideration of productivity, it is customary to measure net production rates because this allows for the energy lost in respiration. Aerobic respiration can be divided into three main stages :

(i) Glycolysis or fermentation of sugar, producing a small amount of energy in the form of ATP, as well as suitable organic acid precursors for the bicarboxylic acid cycle (TCA).

(ii) Dehydrogenation and decarboxylation of these organic acids generate reducing equivalents for the electron transport chain, giving off CO_2 as a by-product.

(iii) The electron transport chain, comprising a number of carriers and co-enzymes, has the function of coupling oxidation of reducing equivalents (2H) to the synthesis of ATP. The process is referred to as oxidative phosphorylation and it is the mechanism by which the bulk of the cell's ATP is generated. These points are summarised in Fig. 8.

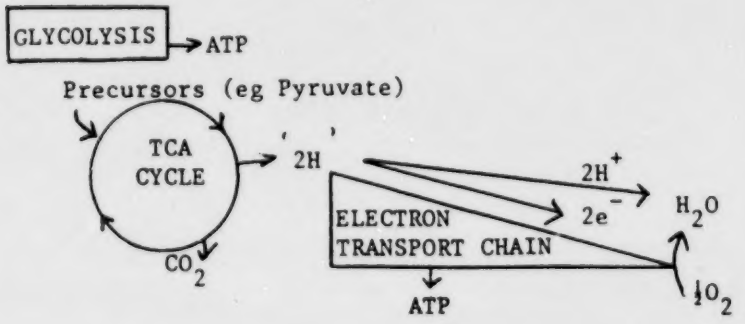


Fig. 8.

Dehygrogenation of TCA cycle acids and oxidative phosphorylation occur within cell organelles called mitochondria. Hence, these organelles are often referred to as the "power houses" of cells.

From the point of view of biofuels, the most significant step is alcoholic fermentation, which does not directly require oxygen. Under anaerobic conditions, ethanol is produced from sugar by organisms, such as yeast and certain bacteria. Ethanol is a useful fuel. The main features of glycolysis and alcoholic fermentation are shown in Fig. 9.

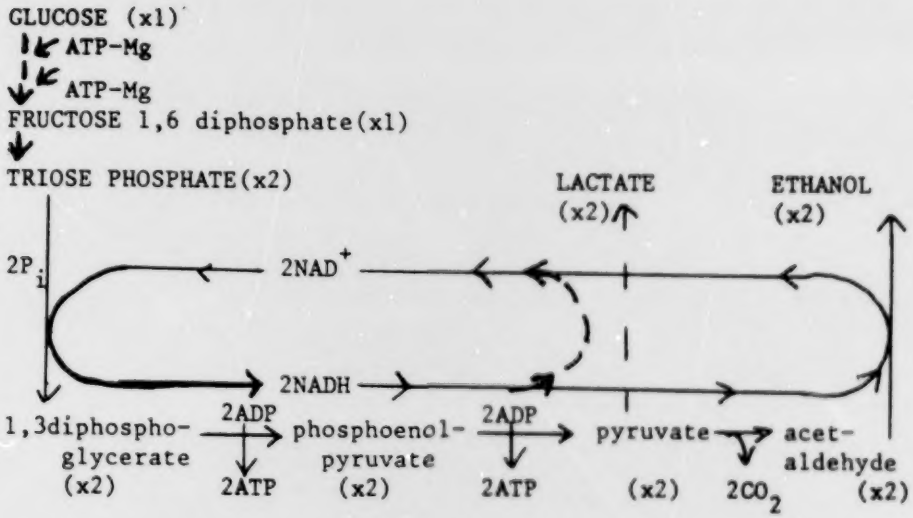


Fig. 9. Glycolysis and alcoholic fermentation.

Lactate production from glycolysis or sugar was first discovered in vertebrate muscle in the early part of the 20th century. Alcoholic fermentation by yeasts has, in principle, been known for centuries.

Pyruvate is a very interesting substance, which has been put to a variety of uses by micro-organisms; some of these alternatives are shown in Fig. 10.

Later, in this section, we shall return to the commercial and economic aspects of fermentation because of the important role played by ethanol in certain countries' (e.g. Brazil) energy strategies.

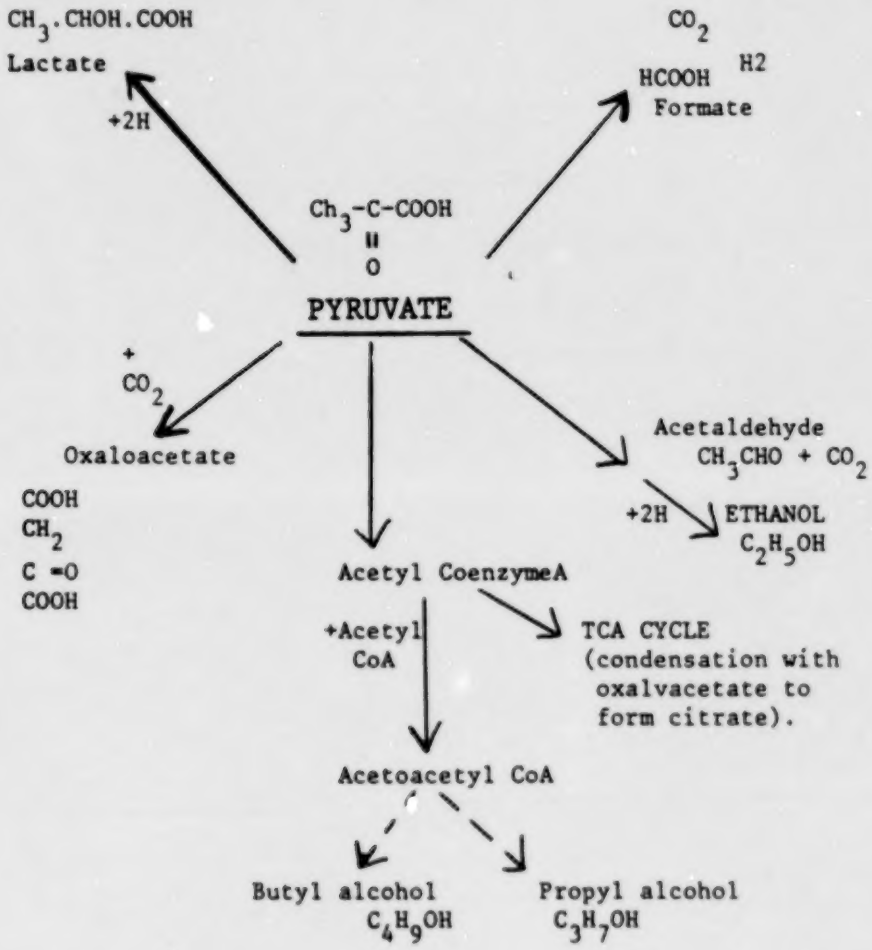


Fig. 10.

Other Biochemical Pathways of Significance to Biofuels

Before moving on to the feasibility of using biofuels, it is important to examine in outline four further examples of pathways generating biofuels or conserving biofuels :

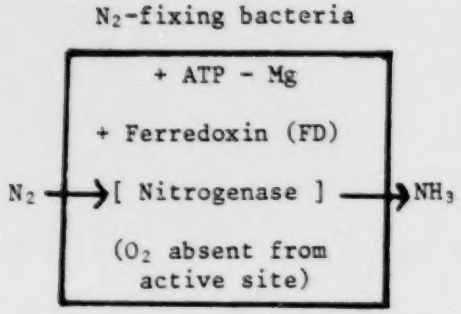
(1) Nitrogen fixation.

(2) Methane production.

(3) Hydrogen production.

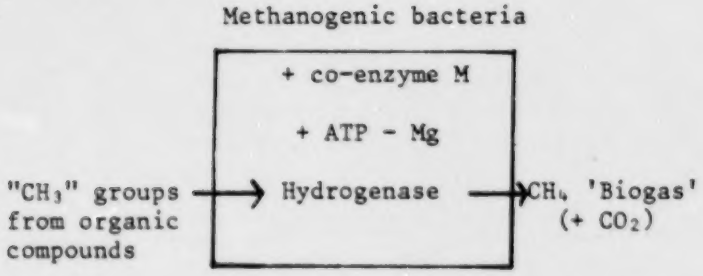
(4) Photosynthesis without chlorophyll.

(1) Nitrogen fixation



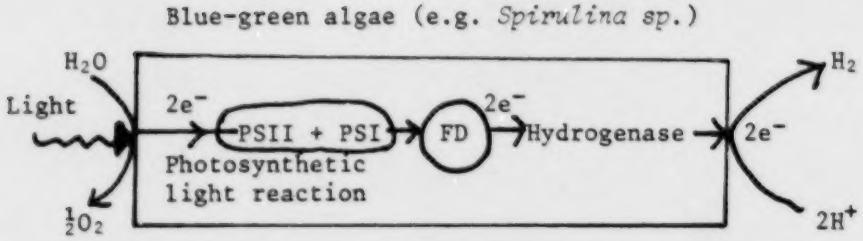
A reduction process

(2) Methane production



A reduction process

(3)



A reduction process

Points to note :

All three processes outlined above are essentially reducing processes involving an enzyme (or composite of enzymes) which must operate in the absence of oxygen. In addition, all three processes involve co-enzymes, such as ferredoxin - an iron-sulphur protein or co-enzyme M. In the absence of light (examples 1 and 2), energy is made available for the reaction from ATP-Mg.

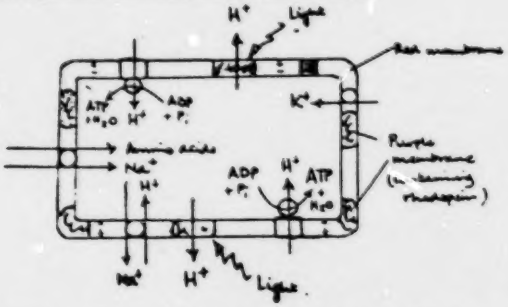
Whilst ammonia is not regarded as a biofuel, it is an important starting point for nitrogenous fertilisers that are so essential for plant growth. The only major alternative to the N_2-fixation process carried out by certain living organisms, is chemical catalysis. Such processes require high temperature and usually high pressure, and this involves an expenditure of energy from fossil fuel sources.

Methane production by anaerobic bacteria has been shown to be of great value, particularly in certain Third World countries. Details of 'biogas' generators, etc. will be discussed later.

The 'hydrogen economy' is another feasible line of technology for the future. Some blue-green bacteria generate hydrogen by linking photosynthesis with a hydrogenase. In other instances, hydrogen can be generated photosynthetically without using chlorophyll or an electron transport system (see (4) below). The organisms responsible for this type of metabolism are species of *Halobacterium*. These bacteria normally live in water where the salt concentration is high (2 M and above) but oxygen is low. In situations where light is present but oxygen concentration is low, protons are "pumped" to the outside of the cell at special points across the membrane known as the purple membrane. In these areas, the pigment rhodopsin is found, which closely resembles the pigment found in the retina of the mammalian eye.

Briefly, the significance from the bacterial cell's standpoint is that it can use the proton gradient (and the small potential difference which also results across the membrane) to generate ATP at other specific sites in the membrane (ATP synthetase sites). ATP is, of course, the chemical energy 'currency' employed when work must be done by living cells. In this respect, the proton gradient established in *Halobacterium* has features in common with the proton gradient established across the inner mitochondrial membrane and the granal membranes of chloroplasts, i.e. ATP is generated. Furthermore, the light-driven extrusion of protons also aids in the active movement of other substances across the cell wall (e.g. amino acids, Na^+ extrusion, etc.).

(4) Photosynthesis without chlorophyll



The *Halobacterium* membrane showing light-driven proton movements. (Redrawn after Prebble, J.N. (1982), *Chloroplasts, Mitochondria and Bacterial Membranes*, Longmans).

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CHAPTER 3

Biofuels

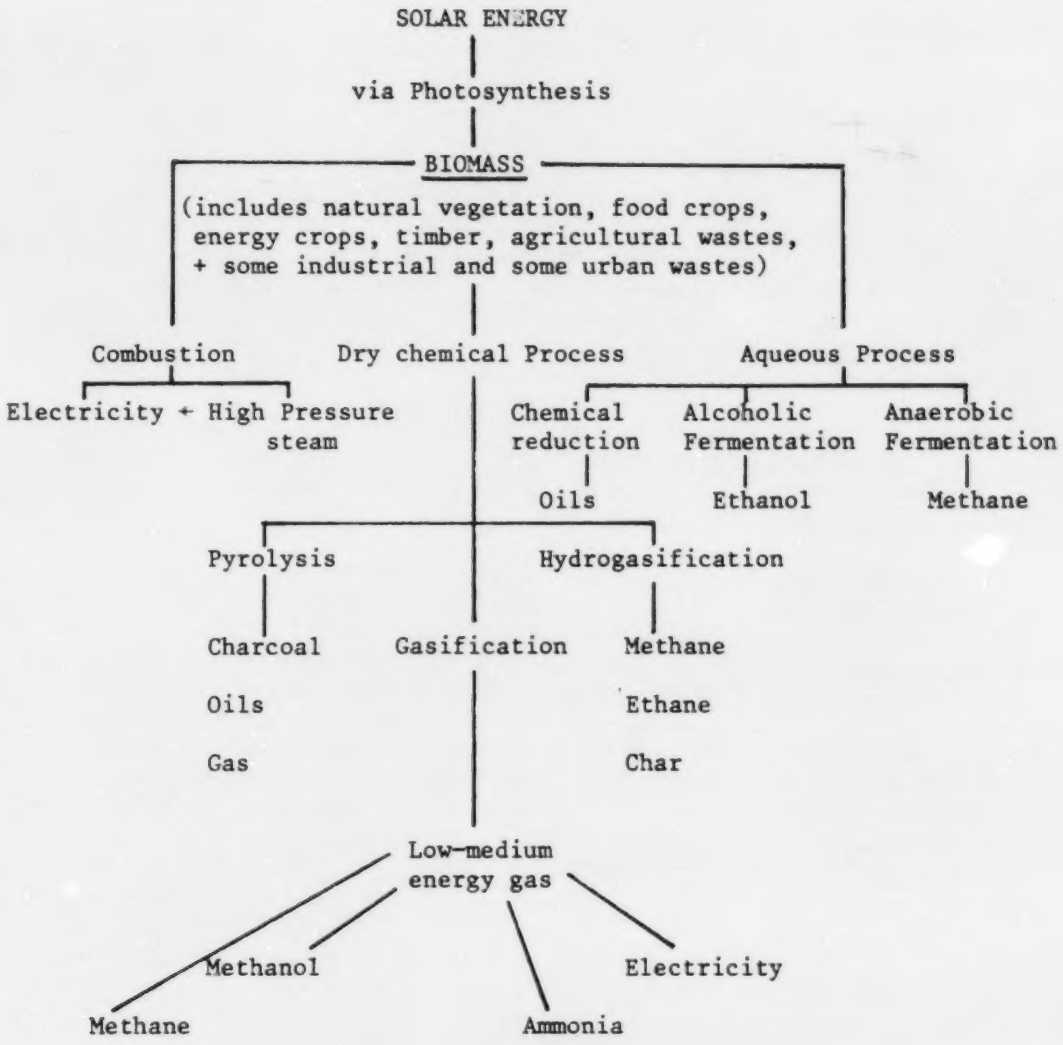

Fig. 11. Possible options for the conversion of biomass to energy. (After Slesser & Lewis (1979), *Biological Energy Resources*).

In looking at the options for converting biomass to fuel energy (Fig. 11), it is necessary to look at (i) the value of the product; (ii) the efficiency of conversion; and (iii) energy input : energy output.

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Consider :

(1) Combustion of biomass to produce steam or electricity; under controlled conditions this is a most efficient conversion process.

Options : (a) Water pipes in the walls of the incinerator produce steam at high efficiencies;

(b) combustion of organic matter with some coal in a conventional power plant;

(c) fluidized bed system for wood chip combustion.

(2) Pyrolysis of wood is an ancient industry, involving the distillation of wood at 300-450°C, in the absence of oxygen. Oils are formed which can be used as fuel oil extenders, but which are not suitable for refinement. Char is also produced, which, when burnt as a solid fuel, has greater energy density than wood.

(3) Gasification is an elaboration of (2), whereby higher temperatures and pressures are employed in the presence of limited oxygen supply. Initially, an H_2/CO gas mixture is produced with traces of CO_2, methane and nitrogen. This low-energy gas can then be used to generate methanol (Fig. 12). Further distillation of the methanol gives rise to an alcohol with 98% purity. The petrochemical industry can then convert methanol into petrol directly using zeolite catalysts, or alternatively convert the original CO/H_2 gas mixture to methane (CH_4). Furthermore, the hydrogen from the mixture will react with N_2 in the presence of iron oxide at high temperatures and pressures to produce NH_3, the starting point for many fertilisers.

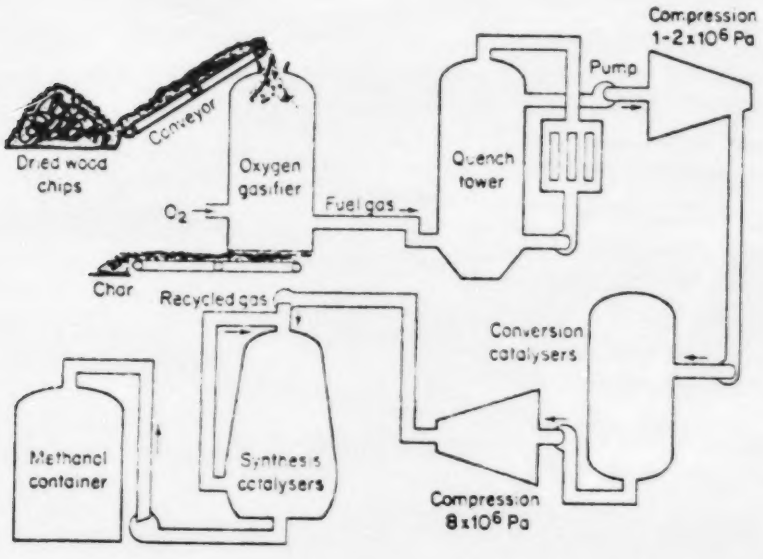

Fig. 12. Gasification of wood to synthesis gas and catalysis to methanol. (From Lewis, C. (1983), *Biological Fuels*, Studies in Biology No.153, Edward Arnold.

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(4) Hydrogasification can convert biomass to methane and ethane by reduction with hydrogen when the temperature is raised to 540°C and the reaction subjected to high pressure.

(5) Chemical Reduction of aqueous biomass by physical and chemical means produces a mixture of fuel oils, but like most of the processes outlined above requires a considerable energy output in the form of high temperature and pressure, which does not make it especially economical, even though the energy content of the oils is quite high.

As a result, most of these processes are likely to be unattractive to Third World countries. A possible exception is producer gas (i.e. H_2/CO mixture), which could be valuable where conditions for biogas production are poor.

In the main, Third World countries are looking at, or currently using, biogas generators or fermentation processes. In addition, very simple technologies, such as cutting peat or making "dried biomass briquettes" from a locally-abundant crop, are used. For example, papyrus is being exploited in certain parts of Africa which verge on lakes and waterways.

Whilst the above-mentioned energy conversion processes indicate the range of technologies available to the world in general, the two most significant processes with respect to the Third World are (i) anaerobic digestion yielding 'biogas' and good quality fertiliser; (ii) alcoholic fermentation producing ethanol and other by-products.

The basic chemistry of these two processes has already been dealt with. What we now need to consider is the technology required, the local resources available and the costing.

Methane or Biogas Production

In S.E. Asia, small-scale biogas generators are extensively used. For example, there are about 80,000 generators used in India and many more in China. The design of the generator varies according to whether good yields of gas are required or good yields of fertiliser. The majority found in India are designed to give good gas yields and therefore have variable volume with constant pressure (Fig. 13A). The Chinese design (Fig. 13B) operates with constant volume but variable pressure and is first and foremost a fertiliser generator. The input material to the tank is more variable, including waste vegetable matter, animal dung and human faeces.

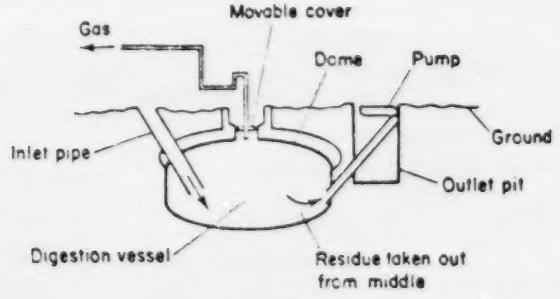

Fig. 13A. CHINESE

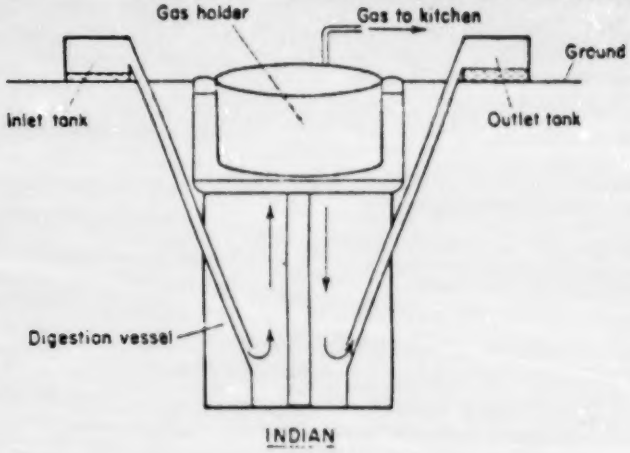

Fig. 13B.

From Lewis, C. (1983). *Biological Fuels*, Studies in Biology. No. 153, Edward Arnold.

In the situation where high 'biogas' yield is required, it is important that the carbon : nitrogen ratio of the slurry material fed to the digester is about 30 : 1. Higher nitrogen values increase the ammonia content, which has a toxic effect on methanogenic bacteria.

The bacterial flora within the anaerobic digester consists of a number of species, which broadly carry out four consecutive processes :

(1) Enzymatic hydrolysis of insoluble polymers, such as cellulose into soluble sugars and other soluble organic substances.

(2) The fermentetion of these products to organic acids (mainly acetate and propionated acid plus hydrogen.

(3) Conversion of organic acids to methane and CO_2 by methanogenic bacteria, within the liquid phase.

(4) Physical transition of products from liquid to gaseous phase.

Advantages of anaerobic biogas generators

(i) Relatively cheap.

(ii) Versatile: a wide range of waste or raw materials can be used.

(iii) Feasible on a small scale or large scale (municipal sewage).

(iv) Work at modest temperatures 30°-50°C.

(v) pH is not very critical; generators can therefore operate in the range pH 6.0 to 7.6.

(vi) Batch, semi-continuous, or continuous fermentation can be selected.

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Disadvantages

(i) Best adapted for warm climates, even though subterranean location of the plant reduces heat loss and some heat is gained through the overall reaction being exothermic (temperature should not fall much below 30°C).

(ii) The 4 chemical processes are slow and time spent within the digester may be several weeks. This has a number of knock-on effects, such as a larger container volume to handle a certain amount of waste feed.

(iii) The added complication of having to remove CO_2 from the gas mixture, where it can contribute one-third of the total.

In Western Europe and North America, municipal waste has been subjected to digestion by methanogenic bacteria, using tanks of much greater capacity (approx 3000 m^3) as compared with some of the tanks in rural India with a capacity as small as 3-5 m^3.

As can be seen, the process does make several demands for an energy input, not the least of which is the shredding and breakdown of cellulosic material found in wood, paper and cardboard. Nevertheless, some of the energy derived from methane can be used to provide the energy necessary for its own formation. Although municipal waste provides the bulk of material, agricultural wastes, such as cattle, pig and poultry manure, producing sewage sludge, are mixed with the predigested waste to yield methane in the digester tank. The CO_2 and small amounts of H_2S are subsequently removed from the methane. Fortunately, only modest temperatures (between 35-38°C) are required for anaerobic digestion. Depending on the solid waste fed to the plant, somewhere between 0.15 and 0.74 m^3 of methane kg^{-1} dry solid can be generated. Put another way, from an input of 900 tonnes of municipal waste about 4 TJ* of energy are produced each day.
* (TJ = terajoules = 10^{12} joules of energy).

Whilst methanogenesis plays an increasingly important role in rural communities of the Third World, it is by no means confined to these situations. Many more countries are setting up pilot plants, and indeed large scale plant, to generate methane from urban or municipal waste. The dumping, burning and burying of waste, which have traditionally been the methods of disposal, reclaim or recycle very little and are certainly not processes that generate useful energy. Furthermore, available land suitable for these purposes becomes increasingly scarce near urban conurbations. The major problem with municipal waste is the need to sort and separate the various non-digestible materials from those than can be used in the digester. Fig. 14 shows the various stages involved in generating methane from municipal waste.

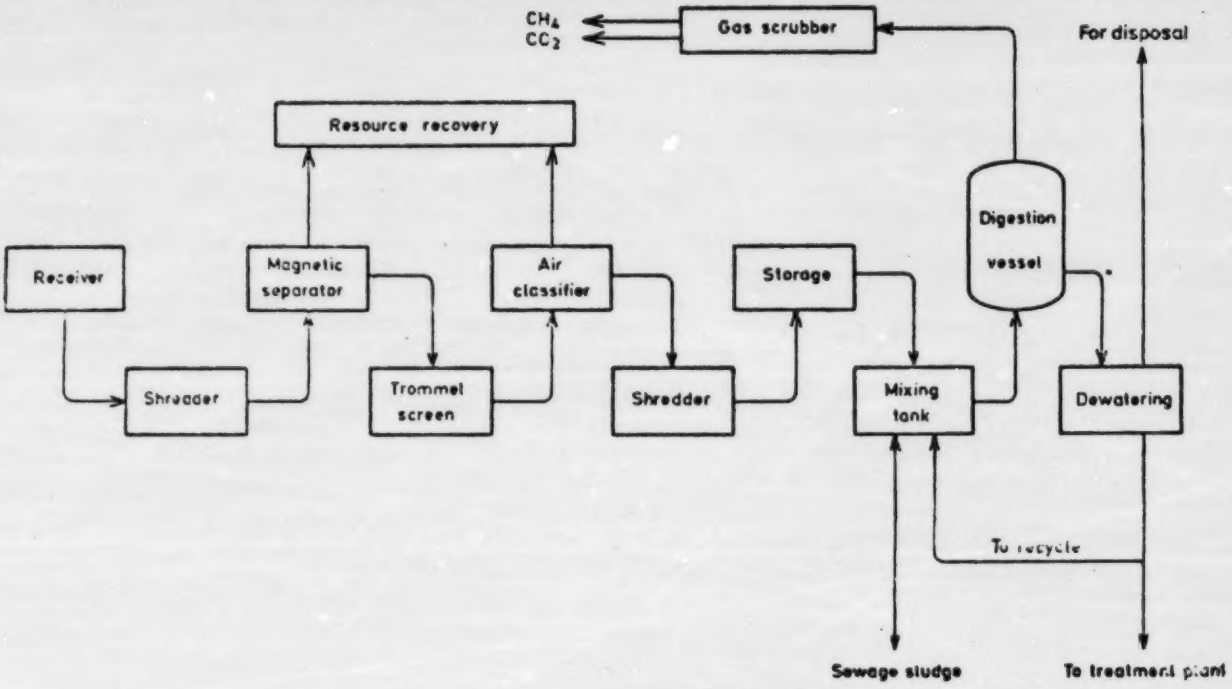

Fig. 14. From Slesser & Lewis (1979), *Biological Energy Resources*, Spon.

Considerable amounts of methane are generated 'naturally' from a number of sources, as shown from the table below, but much of this sizeable potential energy cannot as yet be harnessed.

Methane released into the atmosphere from the following sources :

	Amounts produced in million tonnes each year
Fermentation in the guts of ruminants	101-220
Paddy fields	280
Swamps and marshes	130-260
Freshwater lakes	1.25-25
Coal mining	6.3-22
Lignite mining	1.6-5.7
Industrial losses	7-21
Automobile exhaust	0.5
Volcanos	0.2
Other sources	5.3-16.5

Data source: Methylotrophy & Methanogenesis: P.S. Large (1983), Van Nostrand Reinhold (U.K.) Co. Ltd., p.6.

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Alcoholic Fermentation

Alcohol as a fuel source is primarily generated from sugar cane. Other sources are cassava and sorghum or any other form of low-cost sugar/starch feed that is readily available to the fermentation plant. If starchy substances, such as potatoes, maize or cassava, are used, acid hydrolysis is a necessary prerequisite to alcoholic fermentation. Most fermentation plants are batch operations but continuous or semi-continuous productions are also possible. The latter suffer the disadvantage of requiring scrupulous sterilization procedures, which of course are energy consuming, even though productivity may be increased by up to 2% and the fermentation time virtually halved. A fairly typical sugar-cane fermentation plant is diagrammed in Fig. 15.

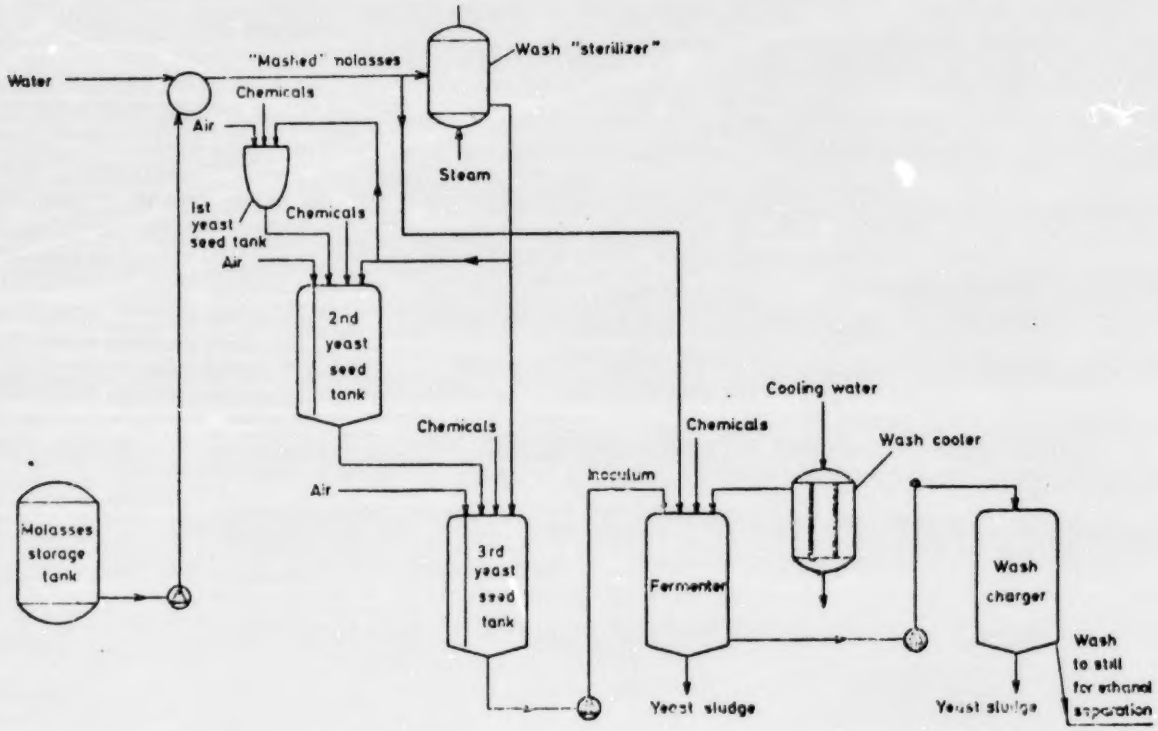

Fig.15. Ethanolic fermentation of sugar cane molasses

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In order to obtain a good energy output : input ratio of the fermentable material, it is important that minimum pretreatment is involved. Cellulose or lignocellulose derived from wood, paper and straw are extremely abundant but require extensive treatment in the form of milling and grinding followed by acid hydrolysis or enzyme treatment. Enzyme digestion is the least energy-demanding but slow. It is particularly slow if the cellulosic material is not finely shredded. The enzymes used are normally fungal cellulases (see Fig. 16). Mechanical and chemical treatments, by contrast, are much faster but more energy-demanding, resulting in poor energy output : input ratios. A major breakthrough would be to find a low-energy cost technology, producing rapid and efficient pretreatment of straw, wood and paper, with small capital outlay!

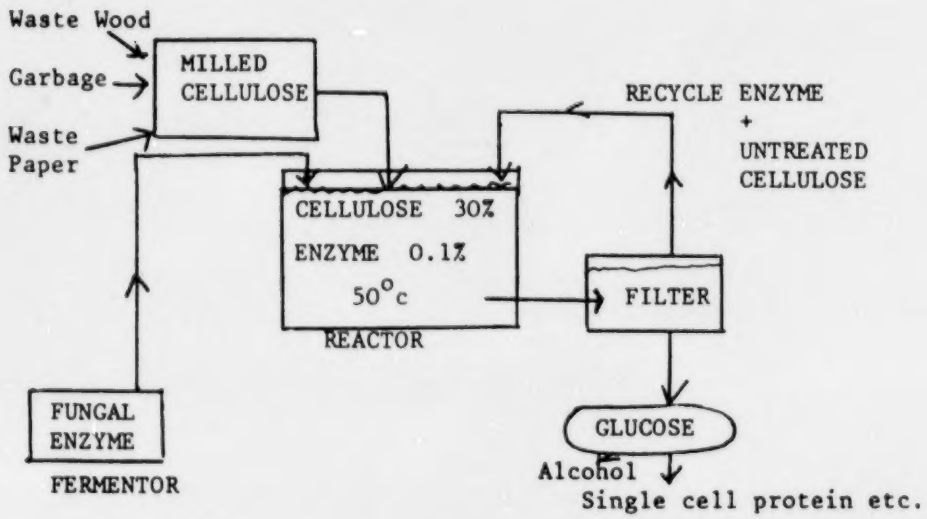

Fig. 16. Fermentation : Cellulose → Glucose.

Looking realistically at the energetics of the problem, it is unlikely that photosynthetic efficiency is much above 2% in any green plant under field conditions. The efficiency of carbohydrate fermentation to ethanol is no better than 30%. Correspondingly, the overall efficiency of solar energy conversion to ethanol is less than 1%. When this figure is compared with the land requirement of growing fuel-crops, few countries could replace their current oil imports by being self-sufficient in ethanol production from biomass. Only countries like Brazil, with outstanding natural resources, extensive land area and suitable climate, could in theory take up the challenge. Currently, Brazil has reduced its oil imports by about 20% and at the same time converted motor engines to accept a blend of petrol with ethanol in a ratio of 4 : 1. In the future, it is likely that most new cars will be designed to run on alcohol alone. One advantage of ethanol is that it causes no pollution, even though it is energetically less efficient than petrol on a volume to volume basis.

The massive National Alcohol Programme launched in 1975 could in theory produce all the ethanol which Brazil requires from about 0.3% of the land area. Other less well endowed countries can only really look to improvements in digestion, fermentation and distillation to receive some benefit to their energy budget from alcohol fermentation.

To complete this section, we should look at some simple, but arily essential, economic and energetic considerations.

Economic considerations are very important to small communities contemplating the setting up and use of a biogas plant. They need to consider (A) what capital investment is needed; (B) what the operating and maintenance costs are likely to be; and (C) what receipts are likely from sales of products.

Table 3. Biogas economics.

A.	INVESTMENTS
	Fixed capital - plant, storage
	Working capital + interest
B.	OPERATING COSTS
	Purchase of waste
	Plant and machinery maintenance
	Fuel
	Staff/labour
	Transportation and distribution
	Water/chemical requirements
	Land taxes and depreciation costs of plant
C.	RECEIPTS
	Sale of gas
	Sale of fertiliser
	Gross Annual Earnings = C
	Net Annual Earnings = (C-B)-A

Likewise, energy budget must examine the energy expended to the energy produced (Table 4).

Table 4.

Alcohol production - Energy balance

If 1 kg ethanol = 29.7 MJ kg^{-1}

	kg	MJ
Fermentable sugar	-	-
Bagasse	-	-
Urea	-	-
o-phosphoric acid	-	-
$MgSO_4$	-	-
H_2SO_4	-	-
Antifoam	-	-
Water	-	-
Stainless steel tank	-	-
Structural steel	-	-
Cement	-	-
Fuel oil	-	-
Electricity	-	-
	y kg	x MJ

Energy expended = $\frac{x}{y}$ MJ kg^{-1}

Net energy obtained = $(29.7 - \frac{x}{y})$

Of necessity, these two tables are presented in simplified form but they point to some of the factors that need to be considered if biomass energy is to be used by a small or indeed large community.

Disadvantages of biomass as a fuel

Energy from biomass looks an attractive proposition, primarily because it is generated from sunlight, which appears to be limitless and, from a simplistic point of view, 'free'. Even if exploited on a large scale to provide energy, it is likely to be relatively non-polluting.

Nevertheless, we also need to consider the disadvantages both at present and in the future.

(i) At present fossil fuels, hydro-electric power and, to some extent, nuclear power, are more readily available and more economical. The attraction of biomass will increase as these other forms of energy, currently available, become more and more expensive.

(ii) Although energy from biomass on a large scale is likely to be non-polluting, it seems certain that it would have considerable environmental impact, especially in terms of changes in land use.

(iii) Plants are inefficient collectors and conservers of sunlight energy: the system ultimately relies on photosynthesis.

(iv) If we calculate (a) present-day energy consumption of populations in various countries; (b) the energy equivalent to that consumption in terms of biomass; and (c) the land area required to grow 'fuel crops':

Then if 10 barrels of oil are equivalent to 65 G Joules hectare^{-1}yr^{-1}, a country like Zimbabwe (Rhodesia), using about 10^8 G Joules yr^{-1} would only require 4% of its 375,000 km^2 of land. Austria with 81,800 km^2 of land (much of which is mountainous) and a population using 3.2 x 10^8 G J yr^{-11} of energy, would need to put aside 60% of its land for fuel crops. Belgium, with only 29,400 km^2, but with a fuel consumption of 11 x 10^8 would require 580% of its land!! The United Kingdom would not fare much better; even if 1% of the solar energy were fixed by plants and every bit of U.K. land used to grow fuel crops, it would only supply just over half of the 1978 fuel consumption. Even the vast land resources and favourable climate of Brazil has only currently reduced the oil import by 25%, although in theory Brazil could grow sufficient crops to replace all of its oil imports. On the other hand, most of the developed countries produce phenomenal quantities of waste paper, only a fraction of which is recycled or used for biofuel (e.g. the USA produces about 2.2 x 10^9 tonnes yr^{-1} of waste paper and the U.K. about 7 x 10^6 tonnes yr^{-1}).

(v) Another disadvantage is that most biofuels have only a modest thermal content compared with fossil fuels.

(vi) Biomass often has a high moisture content and this has the effect of inhibiting combustion and increasing energy loss via latent heat of steam.

(vii) Biomass is normally widely dispersed, has low bulk density which necessitates the use of larger equipment for collecting, handling, storage and eventual treatment of the material.

(viii) Biomass is rarely homogenous in physical form, neither is it free-flowing (like oil). This means that any automatic feed to combustion plants or fermentation is difficult.

Integrated Energy Farms

So far, we have talked about biologically derived energy in separate 'packages', i.e. photosynthesis, respiration, fermentation, methanogenesis, etc. The concept, and indeed small scale reality of a self-cycling energy farm has attracted much attention. Essentially, it combines a series of biological processes, relying on some capital investment and initial energy expenditure in manufacturing the various reaction tanks, but thereafter exclusively utilising the energy from sunlight and waste material. A simple scheme is depicted in Fig. 17. The advantages of such a scheme are obvious, i.e. it is self-sufficient and self-maintaining. The disadvantages are primarily a matter of co-ordinating the rate of one set of reactions in one tank with those in other tanks to ensure that no "bottle-necks" occur. As the size of the self-cycling energy farm is scaled up for greater production, the "bottle-neck" problems become more acute. Rates of reaction need to be carefully monitored by computer and transfer from one tank to another also computer-controlled. Nevertheless, it offers exciting prospects for the future and several countries are currently investigating pilot schemes.

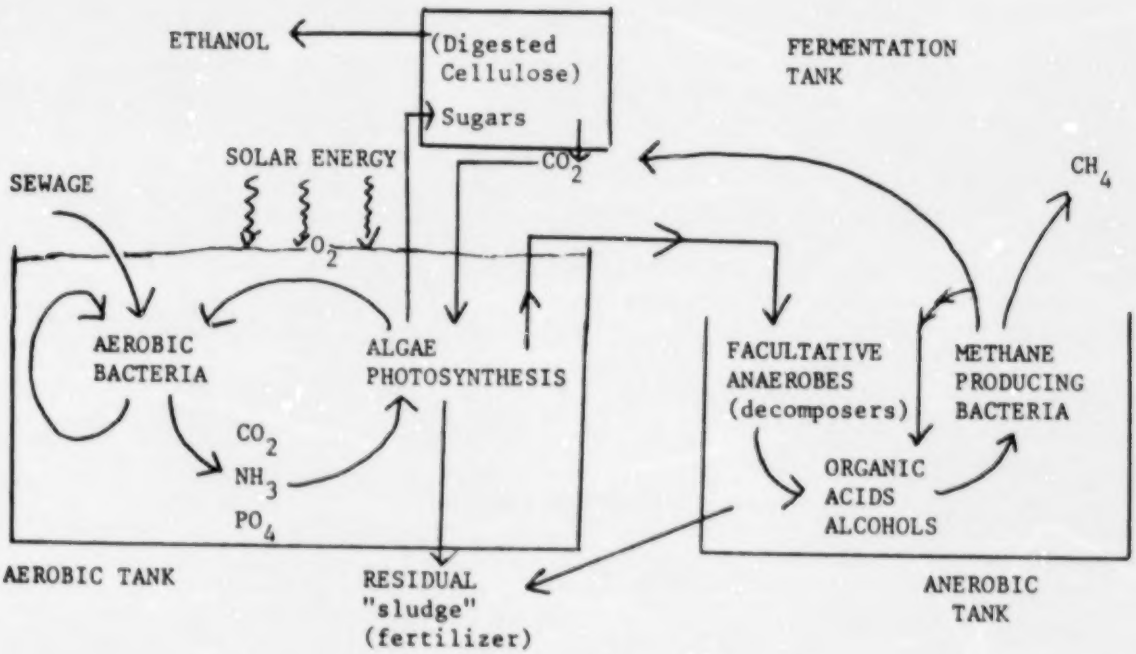

Fig. 17. Self-cycling energy farm.

Energy farming of the oceans

As indicated earlier, productivity in the oceans of the world is considerable. From a practical standpoint, it is only possible to consider the organised growth of certain marine algae along coastal

water for conversion to biofuels. There are two reasons for this : (1) the shallower "upwelling" areas around coasts are richer in accessible nutrients and sunlight; (2) the biomass produced in the open oceans is far too widely dispersed and therefore impracticable for collection and transportation in quantity.

Pilot projects in California, using prolifically growing giant kelps (*Macrocystis pyrifera*) appear to offer promising prospects. Basically, the buoyancy of the kelps is assisted by a network of support lines situated and maintained along the cost. To facilitate nutrient supply, nutrient-rich waters at depths of about 300 m are made available to the kelps by pumping, which of course utilise energy. However, photosynthetic efficiency is improved as a result and is probably as high as 2%. The kelps are harvested and dried to give biomass, which can then be subjected to anaerobic digestion producing methane, as well as valuable animal feedstuffs, fertiliser, important salts and iodine.

The scheme has met with several teething troubles but offers interesting potential for the future.

Silviculture and short rotation forestry

Several countries, particularly Canada, Sweden and the United States are experimenting with fast growing, high yielding trees such as poplar, eucalyptus species and willow, as examples of short rotation energy plantations. The basic ideas behind this specialised form of forestry are summarised in Fig. 18.

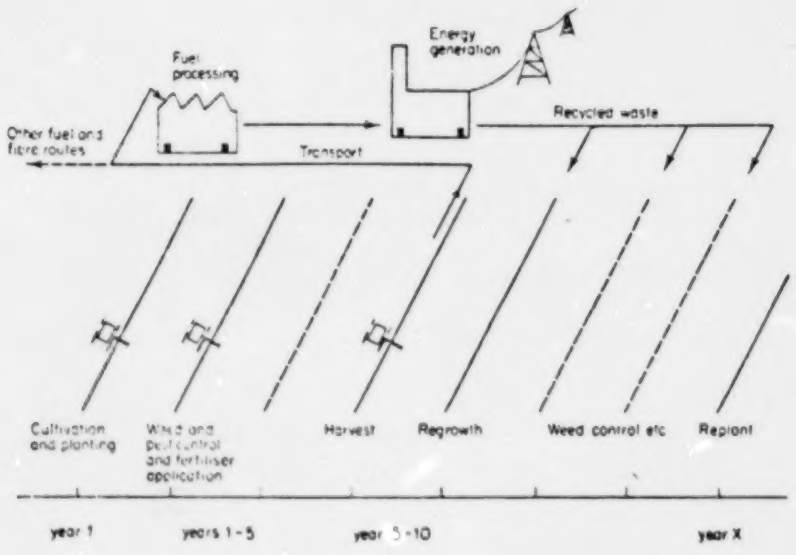

Fig. 18. Elements of a short rotation forestry scheme. From White & Plaskell (1981), *Biomass as Fuel*.

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The major advantages of short rotation crops are that they provide higher yields per unit of land and therefore quicker return on the investment in that land. Rather than a 20-80 year forest harvest cycle, it is necessary to think in terms of 2-4 years. Furthermore, after frequent cropping, the plants selected should be capable of sprouting shoots from the cut tree stumps to eliminate the requirement of replanting after each harvest.

Some of the major advantages of using short rotation silviculture are that the fuels derived are basically non-polluting and cause little or no disturbance to the environment, and waste products can be recycled. Also labour can be reduced by efficient mechanisation in the planting and harvesting of crops.

The major disadvantages of this scheme, however, are : (1) the large land area requirements at low cost; (2) the vulnerability of monoculture to disease and infestation; and (3) the high costs in the first year of setting up the plantation, without any return.

If these schemes are to be successful, then the crop yield will need to be high enough to give a favourable output/input/energy ratio to carry the costs of the scheme and be competitive in prices with equivalent energy derived from other sources.

Future Prospects and Limitations

It is generally true that the cost of extracting useful energy from biomass or photobiological fuels is currently uneconomical compared with the energy derived from fossil fuels and nuclear power. The situation is likely to change in the future with the depletion of fossil plants and the disquiet over nuclear wastes. In the developed countries, methods are currently being researched to extract much greater quantities of oil that the 30% now extracted. Fermentation by bacteria to generate the greater subterranean pressure necessary to 'pump' the oil to the surface is one method being investigated, though the work is still in its infancy.

On an entirely different front, some scientists are attempting to manufacture biodegradable plastics without using petroleum-based resources, since it has been known for some time that certain bacteria can naturally manufacture polymers with properties of plastics. Again, this work is in its infancy and, on current costing is not economical when compared with synthetically made plastics.

Despite these interesting ventures, it is with the Third World countries that we should be most concerned. As fossil fuel becomes more expensive, the energy 'gap' between developed and developing countries becomes bigger. The use of what we might call "non-commercial" energy (e.g. wood, charcoal, dung, etc.) accounts for 70-90% of the total energy consumption for many parts of Africa; about 50 per cent in Asia (excluding China) and about 30% in Latin America. These figures should be compared with the 1-2% used by developed countries. Furthermore, demand for "non-commercial" energy in Third World countries still exceeds supply with the added problems of overgrazing by cattle and goats, as well as competition from food growing requirements for the population.

Nuclear power and electricity are not realistic. Those that are better off could benefit more from biogas technology, but the level of poverty and the problems of distributing energy in rural areas with scattered groups of people basically compound the problem.

What solutions are possible?

A great investment by the developed countries to research and develop new, cheap but effective renewal energy technologies would appear essential. For example, a variety of technologies, using biomass, solar, wind and water power may be appropriate. These should be tailored to suit the specific local conditions. It is clear that each country urgently needs some co-ordinated policy. It may be that fast-growing plant species should be examined more intensely in those climates that are favourable, even though such crops would require proper management and protection. Similarly, re-forestation is urgently required - generally, a five-fold increase to replenish depleted woodland in many parts of the world, but in parts of Africa some five-fold reforestation is needed.

Clearly, improvements in biogas technology provide the most promising way forward for the Third World. China, with its seven million biogas digesters, leads the way in this field. Not only does biogas supply valuable energy, but it improves public health, produces little or no pollution of the environment and yet recycles nutrients in the form of organic "sludge" for fertiliser. Other simple technologies that have been successfully employed on a local scale are solar cookers, which are cheap. but people don't like cooking in the mid-day sun! Alternatively, improvements in wood and charcoal-burning stoves are just about within the means of most rural poor, but still beyond the means of the poorest.

All in all, there are great challenges for science and technology in the future. The biomass energy potential of developing countries is undoubtedly considerable, but how well it will be usefully and cheaply exploited is at present unknown. Furthermore, it is difficult to envisage future biofuel production and consumption patterns of these countries, let alone the methods employed to meet their needs.

CHAPTER 4

A Curriculum Guide to Teaching about Biological Systems as Energy Resources

Science Education

The UNESCO Congress on Science and Technology Education and National Development (Paris, 1981), when discussing the rationale for science and technology education in the perspective of development needs, considered the aims of science education at the secondary level to involve :

1. The acquisition of knowledge and understanding of a range of scientific concepts, generalisations, principles and laws through the systematic study and experience of aspects of the body of knowledge called science.

2. The acquisition of a range of cognitive and psycho-motor skills and processes as a result of direct involvement in scientific activities, procedures and applications in the laboratory and the field.

3. The utilisation of scientific knowledge and processes in the pursuit of further knowledge and deeper understanding, and the development of an ability to function autonomously in an area of science studies to solve practical problems and to communicate that experience to others.

4. The attainment of a perspective or way of looking at the world together with some understanding of how it complements and contrasts with other perspectives or ways of organising knowledge and inquiry.

5. The attainment of a basic understanding of the interaction between science and society and the contribution which science makes to our cultural heritage.

The significance for biology teaching of the chapters on Energy and Ecology, Photosynthesis and Biofuels can be identified by reading them with such aims in mind. In addition, the definition of technology, proposed in a working paper for the Congress, can be helpful in interpreting the idea in aim No.3 of 'practical problems' and in considering the role which technology may have in science education. Technology was defined as "a disciplined process by which the resources of knowledge (of materials, of energy, of the concepts of science of technical concepts, etc.) are used in the practical solution of problems identified by human needs." In the introduction to this volume, Dr. Tribe identifies energy as a human need, and goes on to argue that our knowledge of biological systems may be helpful in devising means of helping to meet this need,

particularly in developing countries. By and large, biology teaching has not concerned itself with technological aspects of energy sources for man's use, although, of course, biomass in one form or another (e.g. wood or fossil fuels) has traditionally formed the basis of man's energy supply. Where these aspects have been located at all in science teaching, they have been dealt with as part of the physics and sometimes the chemistry elements of programmes. For instance,one may have taught about steam engines, or the generation of electricity, and the associated technology, but even here, very little technology, as defined above, has so far been introduced into general secondary curricula in most countries. Technology brings together not only the applications of knowledge but also skills of working in wood, metal and other materials, importantly the creative inventiveness associated with a product that fits a need. If biology programmes in particular, and science programmes in general, are to be improved with a view to better meeting community needs, then the challenge of giving attention to their relationship with productive work and community development, environmental and cultural dimensions and to social relevance will have to be met. A consideration of the significance of the idea of biological systems as energy resources to biology teaching raises all these challenges.

Implications for Biology Programmes

The implications for biology programmes of the issues identified above can be grouped into four sections :

1. The identification of relevant knowledge and understanding within biology itself. Programmes should seek to develop a knowledge and understanding of the sources, methods of uptake, and flow of energy in biological systems. This implies a study of photosynthesis and respiration in an ecological context in order to develop ideas of, for example, biomass, world energy balances, photosynthetic efficiency, and energy flow through ecosystems (see Chapter 1). The selection of organisms for teaching is important in order to bring out the energy-fixing systems that may be of importance as potential energy sources for human needs; for instance, yeast (alcoholic fermentation) (*Crassulaceae* spp (CAM) maize and sugar-cane (C-4 plants), etc. (see Chapter 2).

2. Much of the understanding of energy relationships in living things is dependent upon concepts and principles derived from physics and chemistry and some identification of the conceptual basis in these subjects for adequate development of section 1 above is important. As well as this, an appreciation of the relative significance of biological systems as potential energy sources involves a comparison with other energy sources, such as fossil fuels, nuclear, solar wind, wave and geothermal energies, and an understanding of these derives not from biology but from the physical sciences. Biology programmes must then take into account the structure of courses in physics and chemistry, if they are not formally part of an integrated science programme.

3. Biology courses need to be relevant to the needs of society. Societies are concerned with many issues, among which are health, food and agriculture, natural resources, energy, human settlements and the environment, industrialisation and appropriate technology. Most of these are related to each other, and each could be reflected in school biology programmes concerned with biological systems as energy resources. Two implications arise from this : (a) biology programmes in the selection of content should reflect topics of social concern, and (b) such concerns, having social, economic and cultural, as well as scientific, dimensions, should be presented in biology courses in such ways as to give pupils some experience of decision-making.

4. Biology courses need to encourage the application of knowledge to practical purposes; that is, to incorporate some technology education into the programmes. The identification of practical problems, which can lend themselves to a successful technological appraisal by pupils, is likely to be most effective with examples of the local community, e.g. looking for ways of supplementing the energy resources of a community dependent upon firewood (see p.2).

Blum (1982), in discussing the question of relevance of biological knowledge to community development, suggests a model to show how such knowledge relates to community issues (Fig. 19). Such a model may be helpful when considering the four sections noted above in relation to developing biology programmes.

The selection of content and the development of teaching programmes must be a constantly evolving process. Where new ideas in the sciences are matched by new methods of doing things in technology, the impact on education will be specially significant, not least at present in relation to energy issues, but any attempts to improve biological education should be considered in the context of the whole curriculum. This may involve the exploration of scientific ideas across the curriculum; for instance, in the context of such subjects as social studies, home economics and technical studies. Equally, this in turn may involve an exploration of ways in which ideas from other disciplines can be incorporated into the formal curriculum of the sciences. Integrated science courses are a very effective means for teaching biological topics, such as that dealt with in this volume, within a comprehensive scientific context, and because of this they also lend themselves usefully to developing social and technological dimensions. Hofstein (1979) has argued that since modern technology is an inescapable component of modern society, the integration of technological topics within an inter-disciplinary science curriculum may, if it coincides with students' interests, help in fact to increase students' motivation. At the same time, the students' creativity may be fostered through projects that link school activities with the external world." He goes on to suggest that "in developing countries, it should be easier to relate science to technology by drawing attention to the way in which science is used for the benefit of mankind". The stated aims of most integrated science projects since 1970, as identified in the International Clearing House Reports (Lockard, 1977) are to open

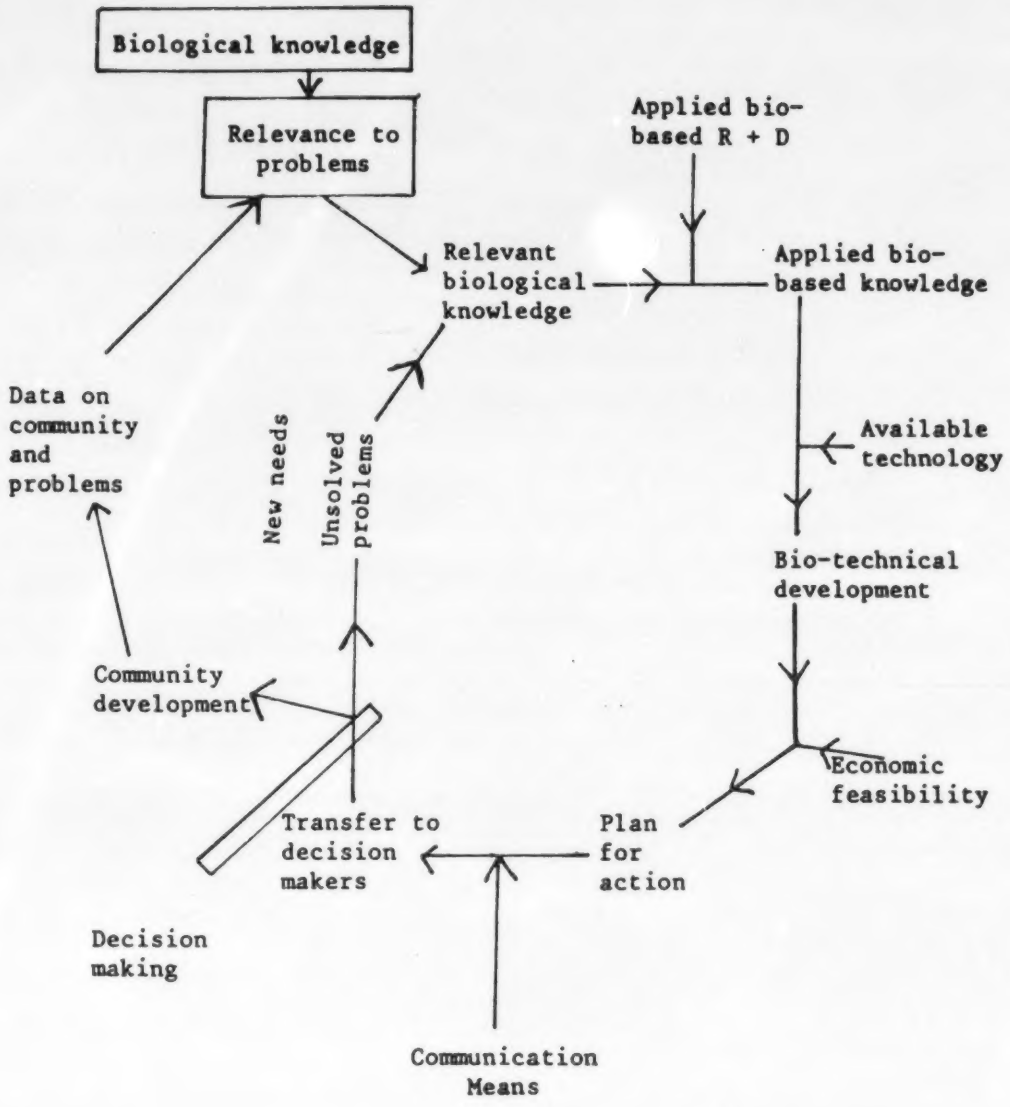

Fig. 19. Biological knowledge to Community Development Cycle (Blum, 1982).

a window into the world outside the school laboratory (Coulson, 1972) and to link the sciences with technology so that the student will get a comprehensive, complete and balanced view of the nature of science as a human enterprise (Richmond, 1971).

Other characteristics in contemporary science curricula development that may be helpful to teachers seeking to implement the implications discussed above are :

(i) science programmes are being designed with a more open and flexible structure; they are less linear, often modular, and allow a study in depth of specific themes;

(ii) such themes are usually across the sciences and often derive from issues of social concern, such as health, nutrition, energy, etc.;

(iii) work is organised on a more individualised basis or in small groups, lending itself to;

(iv) closely inter-related practical and theoretical work, often of an investigating nature;

(v) teaching materials use a multi-media approach.

More recently, attempts have been made to develop programmes which seek to link science and technology education with productive work and community development. Such an approach is based on the argument that work experience can make science and technology more real; there should be a better match between the products of education and opportunities available for employment; and that links needs to be established between school, industry, agriculture and the local community, if science and technology education are to make a major contribution to community development.

This undoubtedly increases the demand on biology teachers. A teacher of biology to-day may be expected to be :

proficient in biology and to some extent integrated science, combined with having the ability to inter-relate science and technology;

able to interpret and teach in a technological and social context;

to know something of the social and economic implications of science and technology;

competent in a range of teaching skills.

An Asian Regional Workshop was organised in the Philippines by UNESCO in 1980. The workshop was concerned to review biology education at the secondary level. One focus was on environmental issues and biology education. The report of the workshop recommended a range of teaching competencies related to environmental issues and biology education (Table 5) (the basic science teaching competencies are assumed to be also necessary but not included in the table). This illustrates some practical experiences and teaching strategies which one may expect to find in biology programmes concerned with environmental issues, and is an example of the sort of context within which one can usefully teach about biological systems as energy resources.

Table 5.

Environmental Aspects of Biology Education

Concepts / Principles / Topics	Practical experiences	Teaching strategies	Values / Skills
Has sufficient knowledge and understanding of the following: 1. Environmental factors 2. Levels of organization 3. Ecosystem 4. Energy flow and material cycles 5. Harmony and balance in ecosystem 6. Environmental problems and management 7. Healthy environment	Is capable of conducting: 1. Field study on – diversity in natural conditions – density and population of plants and animals (man included) – local ecosystems – local polluted areas – natural conservation 2. Case study on – interaction – pollution 3. Experiment to – measure the composition of air – analyse physical and chemical components of soil – study the effects of light and temperature on organisms – study the increase in population of certain organisms – study production rate – test for air pollutants – measure BOD and COD levels – test the turbidity of polluted water	Has the ability to: – identify and utilize environmental resources to the maximum so that teaching becomes more meaningful and relevant – improvise (whenever possible) the enhancement of the learning situation – utilize innovative evaluation tests, both for student evaluation and teaching effectiveness – use process skills and educational technology - audio-visual aids – plan and execute field study, case study and experiments effectively – relate the principles to values and intellectual skills and highlight social relevance to each topic – use short lectures, demonstrations and group discussions at appropriate places in the scheme of instruction – organize project work, games and simulation studies – organize self-study and individualized instruction	Has the awareness of the: – necessity of population control – solar energy and its abundance – balance and harmony in ecosystem – environmental legislations – hazards of nuclear energy Development of: – dexterity in outdoor experimental skills – correct attitude towards harnessing biomass – global perspective of environment – reasoning power and establishing causality – ability to draw inferences from facts – environmental ethics – proper attitudes towards the use of energy resources Realization of the: – implication to social interrelations – potentialities of man vis-a-vis the environment – interactions of the biotic, abiotic and socio-cultural factors – implications of the levels of organization to population growth and consequences as well as social interrelations

Table 5

Environmental Aspects of Biology Education (cont'd)

Concepts / Principles / Topics	Practical experiences	Teaching strategies	Values / Skills
	– compare the amount of soil organisms in polluted and un-polluted areas – study the roles of plants in preventing soil erosion Construction of – models showing different types of ecosystem – an artificial ecosystem – models showing food chain, food web Depiction and interpretation of data/ information through graphs, tables, diagrams, illustrations, charts		– significance of local ecosystems for the society – significance of recycling and its application in daily life – roles of the students in minimizing pollution – need for conservation – need for every development project to give appropriate consideration to its environmental implications Appreciation of – aesthetic values – conservation laws

CHAPTER 5

Teaching and Learning Strategies

General Considerations

Teaching about energy in a community context involves providing pupils with opportunities of experiences so that they may acquire an understanding of :

(a) a range of scientific concepts;

(b) technology and its potential;

(c) decision-making in a social context.

It is necessary to employ a wide range of teaching strategies in order to provide pupils with adequate learning experiences. Teaching strategies in current use range from a scientific/ descriptive approach to those embracing a concern for social relevance and moral values. Kelly (1980) has described these different approaches respectively as Knowledge Studies and Issues Studies. Knowledge Studies involve inquiry learning, among other things, and Issues Studies involve an exploration of attitudes and values. Meyer (1982), in surveying biology education, suggests that most school systems have reached at least the stage of inquiry learning and many are also exploring an issues studies approach. The implications of the above discussion are that a further dimension needs to be included in the teaching strategies used in biology, if it is to meet community needs; that is, a creative, technological dimension. It may be helpful to see this aspect as relating knowledge studies to issues studies. A study of energy must involve a knowledge studies approach, including the traditional practical inquiry aspects; this could lead either into or arise from a consideration of a community's energy needs. The two aspects come together when pupils engage in activities to help meet the community's needs, i.e. they may explore how the biological waste of a community may be utilised as a potential energy source. One could describe this aspect of the work as Applied Studies. Richmond (1973) has described interesting work on the use of solar energy and, although this is within a physics course, it contains many interesting approaches relevant to a technology dimension in biology programmes. He argues that solar energy is a potential contributor to local and national energy supplies and that its study raises scientific, technical and social questions. At any stage, personal investigations can be undertaken and can proceed to a level of theory and analysis appropriate to the abilities of the investigators. Richmond's work on solar energy is an interesting and pertinent example of applied studies in a science programme.

Teaching Strategies

Teaching strategies concerned to encourage pupils to apply biological knowledge to the resolution of practical problems will embrace knowledge studies, issues studies and applied studies approaches. Such approaches will involve field and laboratory investigations; theoretical exercises; role play debates; simulation exercises; project work involving design of materials and apparatus; reading; and experiential experiences, among others. (A full and useful discussion of methodologies relevant to biology education will be found in Meyer (1982). Skilful sequencing of these various approaches related to pupils' interests and abilities is a significant element in successful biology teaching and maintaining pupils' motivation is very important for effective learning. Ramirez and Castaneda (1974) give useful advice on how to achieve appropriate motivation. They suggest, among other things :

> encouraging independent student achievement and competition between students;
>
> the teacher adopting a consultant role;
>
> encouraging task-orientation and learning through trial and error;
>
> expressing confidence in the pupil's ability to succeed;
>
> giving clear guidance to pupils.

An applied studies approach in biology teaching concerned with the community needs lends itself well to such ideas.

The scientific/descriptive, or knowledge studies, aspects of energy sources is central to an adequate understanding, and here teaching strategies, drawing upon the ideas of Ausubel (1968), on meaningful verbal learning can be very helpful.

Novak (1977, 1978, 1980) has put forward useful concrete illustrations of applying learning theory to the teaching of biology, in which three categories of teaching behaviour operate; that is: the promotion of active reception learning; strengthening cognitive structure; and promoting a critical approach to knowledge.

Decision-making aspects of work in science programmes is relatively new, although some programmes have explicitly incorporated such features. The B.S.C.S. course *Innovations: The Social Consequences of Science and Technology* (McConnell, 1982), teaches a decision-making model, while *Science in a Social Context* (SISCON) *in Schools* (Solomon, 1983) invites students to contemplate how they might put their collective decisions into action. Some educators have urged caution in incorporating work on collective decision-making on science-related social issues into school science. Questions have been raised as to (a) whether the cognitive complexity and "moral maturity" is too demanding at this level (Layton, 1982); (b) what sort of knowledge <u>of</u> and <u>about</u> science

and technology is most useful (Aikenhead, 1980); and (c) what functional knowledge of society is acquired (McConnell, 1982). Experienced teachers, in attempting decision-making instruction in science, have noted a number of potential pitfalls and have suggested that teachers need to be aware that the necessary prerequisite knowledge, in order to make thoughtful decisions on issues associated with science and technology, involves an awareness of (a) the characteristics of science: (b) the characteristics of technology; (c) the limitations of scientific knowledge; and (d) the interactions among science, technology and society. We cannot assume that a deeper understanding of scientific ideas as such by our pupils will lead directly to more thoughtful decisions on social issues related to science and technology; neither should we assume that pupils who can (a) apply scientific and technical principles to an issue in question, and (b) are aware of the characteristics and limitations of science and technology, will necessarily come to a large degree of agreement on a decision to hand. (Indeed, disagreement among the scientifically-literate is sharper compared to the general public over many issues concerned with science and society.) Consequently, teachers, when concerned with issues studies, are not concerned with 'right' answers, and this presents a particular challenge to science teachers experienced largely with knowledge studies approaches. An interesting example of an attempt to deal with decision-making in science is a unit produced at Bath University (U.K.) on decision-making exercises in agriculture (Wells & Crisp, 1976).

Some examples of activities related to biological systems as energy sources

1. Make a model biogas generator

Biogas technology used on a small scale to provide lighting and heat for individual families can be explored by (a) visiting community-size gas plants, if they occur locally, and (b) by inviting pupils to design and build a biogas generator, based on their studies in biology. Fig. 20 illustrates a model generator which can be made out of simple materials. Samples of the gas can be collected by pressing down on the inner bottle, and then tested, using a burning taper.

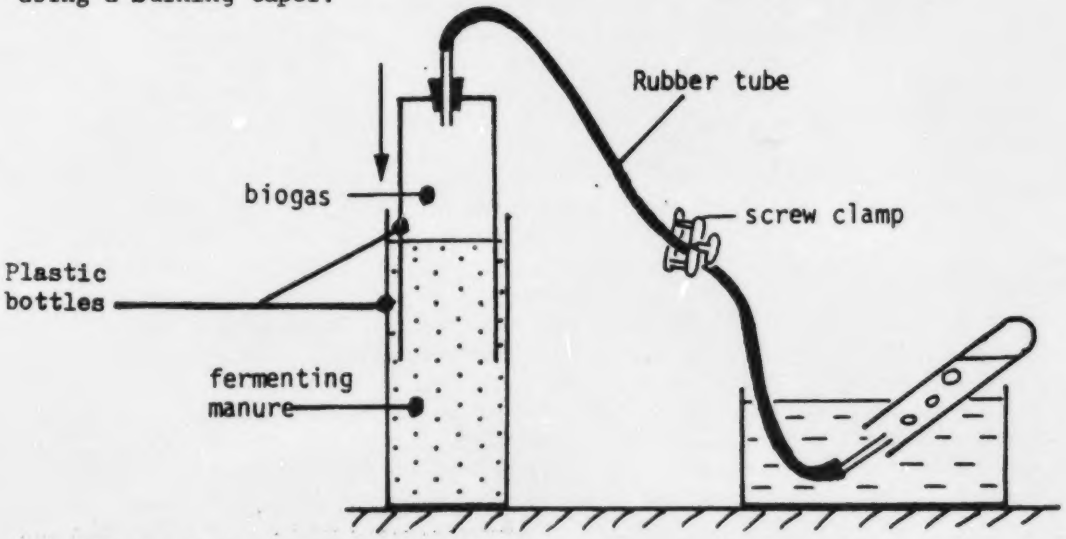

Fig.20 A simple biogas generator.

2. Economics of Fuel Usage

Associated with work on making a biogas generator, pupils can be given exercises, using data, to compare efficiency of fuel use in a simulated situation. A farm with waste organic matter (e.g. a coffee farm with waste husks) may need to consider whether to install a biogas plant or to sell the waste for some other use (e.g. a local clay works may purchase the husks). A biogas plant would enable the farm to replace petrol as the electricity supply for the farm and would provide fertiliser. Installation of the biogas plant would involve borrowing money and paying it back with interest. Such a situation can be used to develop role-playing, quantitative worksheet exercises and simulation exercises. The energy potential of cellulose can be calculated by the pupils, the efficiency of the energy transfer to electricity can also be calculated, and the whole exercise can be related to economic issues, i.e. the capital cost of installation (including interest charges), together with the potential benefit from no longer depending on petrol, versus potential profit from sale of the waste for other purposes.

3. Laboratory Work and Project Work

Investigate the most energy-efficient way of using school land (e.g. cattle, forest, agroforestry = crops and trees).

This may be an overall project which covers laboratory and field investigations into the nitrogen cycle (including looking at leguminous roots); photosynthesis and respiration (including practical work on Crassulacean Acid Metabolism and C4 Photosynthesis to illustrate the efficiency relative to the topic in question) and the use of products. Such a project would cover a variety of teaching strategies and be concerned to deal with ecological efficiency, consumers and food chains, decomposers, biomass and pyramids, as the biological principles used eventually in contributing to making judgements on the best use of the land.

BIBLIOGRAPHY

The aim of this list is to direct the reader to references used in the text and also to sources that are rich in further references, so that bibliographies, resources and curriculum materials appropriate to the reader's own geographical location may be identified. The bibliographies and resource lists in the companion volumes, Ecology, Ecosystem Management and Biology Teaching, and Agriculture and Biology Teaching, have relevant material also.

Addinel, S. & Solomon, J. (Eds.) (1983).
Science in a Social Context: Teachers Guide.
Association for Science Education, Hatfield.

Aikenhead, G.S. (1980).
Science in Social Issues: Implications for Teaching.
Science Council of Canada, Ottawa.

Anderson, J.W. (1980).
Bioenergetics of Autotrophs and Heterotrophs.
Studies in Biology No.126,
Edward Arnold, London.

A.S.E. (1981).
Science in Society: Teachers Guide.
Heinnemann Ed. Books, London.

A.S.E. (1984).
Rethinking Science - Teaching Science in its Social Context.
A.S.E., Hatfield.

Ashby, Ld. (1981).
Science and Political Decisions.
In, J. Lewis (Project Director), *Science in Society: Looking to the Future* (Book L).
Heinnemann Ed. Books, London.

Atchia, M. (Ed.) (1982).
Research in Community Based Biological Education.
IUBS Commission for Biological Education.

Ausubel, D.P. (1968).
Educational Psychology: A Cognitive View.
Holt, Rinehart & Winston, New York.

Barnet, A., Pyle, L. & Subramanian, S.K. (1978).
Biogas Technology in the Third World: A Multidisciplinary Review.
IRDC Document 103e, Ottawa

Berry, D. (1982).
The Biology of Yeast. Studies in Biology No.140.
Edward Arnold, London.

Blum, A. (1982).
From Biological Knowledge to Community Development.
In, Atchia, M. (Ed.) (1982), *Research in Community Based Biology Education*,
IUBS Commission for Biological Education.

Braun, E., Collingridge, D. & Hinton, K. (1979).
Assessment of Technological Decisions: Case Studies.
Butterworth, London.

Bungay, H.R. (1981).
Energy, the biomass option.
John Wiley, New York.

Calvin, M. *et al.* (1982).
Fuel from biomass: Plants can be a direct fuel source.
Biologist 29 (3), 145-148.

Chapman, S.B. (1976).
Methods in Plant Ecology.
Blackwell Scientific, Oxford.

Coombes, J. (1983).
Sugar cane.
Biologist 30 (1), 15-22.

Coombes, J. & Hall, D.O. (1981).
Biomass - an International Journal.
Applied Science Publishers, London.

Cooper, J.P. (Ed.) (1975).
Photosynthesis and Productivity in Different Environments.
IBP Cambridge University Press, Cambridge.

Danks, S.M., Evans, E.H. & Whittaker, P.A. (1983).
Photosynthetic Systems.
John Wiley & Sons

Duvigneaud, P. (Ed.) (1971).
Productivity of Forest Ecosystems.
(Proceedings of the Brussels Symposium, 1969) UNESCO, Paris.

Eijkelhof, H.,Boeker, E., Root, H. & Wilnbeek, N. (1981).
Physics in Society.
Vu Boek Landel/Uitgeverij, Amsterdam.

Ellington, Addinall & Percival (1981).
Games and Simulations in Science Education.
Kogan-Paul

FAO (1979).
Forestry for Rural Communities.
FAO Forestry Department Booklet, FAO Rome.

Fry, J.L. (1972).
Practical Building of Methane Power Plants for Rural Energy Independence.
D.A. Knox, Andover, U.K.

Gaskel, P.J. (1982).
Science, Technology and Society: Issues for Science Teachers.
Studies in Science Education (9) 33-46.

Gates, D.M. (1962).
Energy Exchange in the Biosphere.
Harper & Row, New York.

Gauld, C.F. & Herkins, A.A. (1980).
Scientific Attitudes: A Review.
Studies in Science Education 7, 129-161.

Golley, F.B. (1961).
Energy Values of Ecological Materials,
Ecology 42, 581-584.

Gray, T. (1980).
Biotechnology-Microbiology in Industry.
Fife Applied Science and Technology Project, Kircaldy.

Halacy, D.S. (1977).
Earth, Water, Wind and Sun: Our Energy Alternatives.
Harper & Row, New York.

Hall, D.O. (1979).
Solar energy conversion through biology, Part 1
Biologist 26 (1), 16-22. Part 2 Biologist 26 (2), 67-74.

Hall, D.O., Barnard, G.W. & Moss, P.A. 1982).
Biomass for energy in the Developing Countries.
Pergamon Press, Oxford.

Hall, D.O. & Rao, K.K. (1981).
Photosynthesis (Third edition).
Studies in Biology No.37,
Edward Arnold, London.

Hofstein, A. (1982).
Science Education: Application and Implication.
(Paper presented at Second International Symposium on
World Trends in Science Education, University of Nottingham)
Nottingham.

Holton, G. (1978).
The Scientific Imagination: Case Studies.
Cambridge University Press, Cambridge.

Hurd, P. (1975).
Science, Technology and Society: New Goals for Inter-disciplinary Science Teaching.
The Science Teacher 42 (2), 27-30.

Hurd, P. (1982).
Transformation of Science Education: Challenges and Criteria.
Science Education 66 (2), 281-285.

Jacobson, W.J. (1982).
A generalised approach to societal problems.
Science Education 66 (5), 699-708.

Janis, I.L. & Mann, L. (1977).
Decision Making.
Free Press, New York.

Jones, F.R. (1966).
Farm Gas Engines and Tractors.
McGraw Hill, New York.

Jones, M. (1983).
Papyrus: a new fuel for the Third World.
New Scientist 99 (1370), 418-421.

Jungwirth, E. (1981).
Science Education and Politics.
Science Education 65 (3), 253-258.

Kalra, R.M. (1976).
Meaningful Science Education for Rural India.
Sterling Publications, New Delhi.

Karplus, R. (1978).
Teaching for the Development of Reasoning.
Lawrence Hall of Science, University of California, Berkeley.

Kelly, P.J. & Schaefer, G. (Eds.) (1980).
Biology Education for Community Development.
Taylor & Francis, London.

Kurfman, D. (1977).
Developing Decision Making Skills.
National Committee for Social Studies Yearbook, Washington D.C.

Large, P.J. (1983).
Methylotrophy and Methanogenesis,
Aspects of Microbiology No.8,
Van Nostrand Reinhold Co. Ltd.

Layton, D. (1982).
Science Education and Values Education: An essential tension.
In, Head, J. (Ed.), *Science for the Citizen.*
Proceedings of the UK/USA Seminar,
British Council, London.

Lewis, C.M. (1980).
Alcohol and Methane - Two Biological Fuels for Man.
Biologist 27 (2), 68-72.

Lewis, C.M. (1983).
Biological Fuels, Studies in Biology No.153,
Edward Arnold, London.

Lockard, David J. (1977).
International Clearing House on Science and Maths. Curriculum Developments - Report.
International Clearing House, University of Maryland, USA.

Major, J.K. (1978).
Animal-Powered Engines.
B.T. Batsfurd Ltd., New York.

58

McConnell, M.C. (1982).
Teaching about Science, Technology and Society at the Secondary School Level in the United States. An educational dilemma for the 1980's.
Studies in Science Education 9, 1-32.

Meyer, G. Rex. (1982).
Methodologies for Relevant Skill Development in Biology Education.
Science and Technology Documentary Series No.2, UNESCO, Paris.

Munby, H., Orpwood, G. & Russell, T. (Eds.) (1980).
Seeing Curriculum in a New Light: Essays from Science Education.
OISE Press, Toronto.

National Academy of Sciences (1976).
Energy for Rural Development.
National Academy of Sciences, Washington

Novak, J.D. (1977).
A Theory of Education,
Cornell University Press, New York.

Novak, J.D. (1978).
Applying Learning Psychology and the Philosophy of Science to Biology Teaching.
The American Biology Teacher 42, 148-149.

Novak, J.D. (1980).
Learning Theory Applied to the Biology Classroom.
The American Biology Teacher 43, 280-285.

Novak, J.D. & Helm, H. (Ed.) (1983).
Misconceptions in Science and Mathematics.
Proc. International Seminar, Cornell University, New York.

Papanek, U. (1971).
Design for The Real World.
Thames & Hudson, London.

Postgate, J.R. (1979).
Nitrogen Fixation.
Biologist 26 (4), 165-166.

Ramirez, M. & Castaneda, A. (1974).
Cultural Democracy, Biocognitive Development and Education.
Academic Press, New York.

Reay, J. (Ed.) (1979).
New Trends in Integrated Science Teaching, vol. V.
UNESCO, Paris.

Richmond, P.E. (Ed.) (1971).
New Trends in Integrated Science Teaching, vol. I.
UNESCO, Paris.

Richmond, P.E. (1973).
New Trends in Integrated Science Teaching, vol. II.
UNESCO, Paris.

Sayer, M. (1972).
Technology Appreciation.
School Science Review 54 (189), 795-797.

Slesser, M. & Lewis, C.M. (1979).
Biological Energy Resources.
E. & F.N. Spoon Ltd., London.

Smith, J.E. (1981).
Biotechnology.
Studies in Biology No.136,
Edward Arnold, London.

Spinks, A. (1982).
Alternatives to fossil petrol,
Chemistry in Britain 18, 99-105.

Steinhart, E.E. (1974).
Energy Sources, Use and Role in Human Affairs.
Duxbury Publishers, Belmont, California.

Swift, D.G. (1983).
Physics for Rural Development.
John Wiley & Sons, Chichester, U.K.

Townsend, C. & Phillipson, J. (1977).
A field course based on the community energy flow approach.
Journal of Biol. Education 11 (2), 121-132.

Tribe, M.A. & Whittaker, P.A. (1982).
Chloroplasts and Mitochondria (Second Edition),
Studies in Biology No.31,
Edward Arnold, London.

UNESCO (1980).
Biology Education in Asia.
Report of a Regional Workshop, UNESCO Regional Office
for Education in Asia and the Pacific, UNESCO, Bangkok.

UNESCO (1980).
Linking Science Education to the Rural Environment.
UNESCO Regional Office for Education in Asia and
the Pacific, UNESCO, Bangkok.

Van Buran, A. (Ed.) (1976).
A Chinese Biogas Manual,
ITDG Publications, London.

Walker, D.A. (1979).
Energy, Plants and Man.
Packard Publishing, Chichester, U.K.

Wells, J. & Crisp, S.J. (1976).
The Ridpest File.
Bath University (British Agrochemical Association, Bath, U.K.)

Wheeler, D. & Janis, I.L. (1980).
A Practical Guide to Making Decisions.
The Free Press, New York.

White, L.P. & Plaskett, L.G. (1981).
Biomass as Fuel.
Academic Press

Williams, A.B. (1975).
A method of integrating chemistry subject matter into biological science instruction.
Science Education 59 (2), 167-175.

Woolnough, B.E. (1975).
The Place of Technology in Schools.
School Science Review 56 (196), 443-448.

Ziman, J. (1980).
Teaching and Learning about Science and Society.
Cambridge University Press, Cambridge.